N 63-10782

Crew Performance During Simulated Lunar Missions

MARTIN

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ER 12693

AUGUST 1962

By

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MARTIN MARYIN MARIETTA

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Foreword

The research presented in this report was performed by the Space Systems Division of the Martin Company under Contract NAS1-1861 for the Langley Research Center, National Aeronautics & Space Administration, Langley Air Force Base, Virginia. The program was technically monitored by Mr. Algranti of the Langley Research Center.

Many individuals contributed to the successful completion of the program, and we wish to acknowledge their assistance. The cooperation and contributions of the four NASA crew members, and of Mr. J. Algranti and Mr. H. Hatch, of the Langley Research Center, greatly enhanced the effective conduction of this research program.

The contribution of the various technical consultants are also acknowledged. They are as follows:

Dr. A. Genecin
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We further wish to particularly acknowledge the support and guidance of Mr. L. Sternfield, of the Martin Company, who served as program manager. The contribution of the following Martin personnel are also acknowledged:

Mr. P. Frank - Aerospace Mechanics
Mr. T. Garceau - Aerospace Mechanics
Mr. J. Stricker - Aerospace Mechanics

Mr. G. Rosinger	-	Life Sciences
Mr. R. Hurley	-	Electronics
Mr. L. Oliver	-	Life Sciences
Mr. F. Barbour	-	Manufacturing
Mr. A. Warren	-	Manufacturing
Mrs. A. Phillips	-	Project Secretary

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LIST OF SYMBOLS

V = Vehicle velocity

$\dot{h}$ = Vehicle attitude rate

$\dot{h}_{error}$ = Vehicle attitude rate error

ΔV = Velocity increment during powered flights

ΔVe = Error in powered flight velocity increment

θ = Vehicle pitch attitude

ψ = Vehicle yaw attitude

ϕ = Vehicle roll attitude

$\int_e = \int \sqrt{\theta^2_E + \psi^2_E + \phi^2_E}\ dt$ = integrated root sum square of errors (error integral)

$\dot{\theta}$ = Vehicle pitch attitude rate

$\dot{\psi}$ = Vehicle yaw attitude rate

$\dot{\phi}$ = Vehicle roll attitude rate

θ_E = Vehicle pitch attitude error

ψ_E = Vehicle yaw attitude error

ϕ_E = Vehicle roll attitude error

$\int_{t_1}^{t_2} \dot{w}\ dt$ = Propellant consumed between t_1 and time t_2

x, y, z = Rendezvous vehicle displacement in x, y, z coordinate system. The origin of the x, y, z coordinate system is at the mass center of the "Mother" ship in circular lunar orbit. The z axis is along the radius vector: from the center of the moon to the "Mother" ship. The y axis is perpendicular to the z axis in the direction of motion. The x axis completes the right-handed coordinate system.

$\dot{x}, \dot{y}, \dot{z}$ = Time rate of change of rendezvous vehicle x, y, z coordinates

$\int Vhe$ = Factor indicating accuracy of re-entry trajectory control

$T/W_{initial}$ = Initial thrust-to-weight ratio

Summary

The study described in the present report is concerned with crew performance during simulated lunar landing. Four experienced test pilots participated as crew members during three separate, simulated lunar flights. Two of the flights were of approximately 3-1/2 days duration while the third flight was of seven days duration. Two interconnected simulators, a main vehicle and an excursion vehicle, were utilized to evaluate crew performance during lunar landing. The display and control inputs and outputs were monitored and controlled by a simulator control room and analog facility.

The crew system tasks during the flights consisted of flight control tasks, navigation tasks, and systems management tasks. Further, a battery of behavioral response tasks and a maintenance task were also included. One important aspect of the simulation tasks is that they were performed in accordance with a realistic lunar trajectory and within one of a possible number of spacecraft internal configurations. Vehicle dynamics for all mission phases from earth ascent to lunar landing to earth re-entry were also realistic.

Comparison of performance during each of the flights was based upon baseline performance collected prior to the flights. Crew familiarization training and the collection of baseline data spanned approximately 10 weeks. Other variables investigated in the present study consisted of a psychological and medical evaluation, an evaluation of a 24 and 26 hour duty cycle, and an evaluation of physical endurance at the end of each flight. The first simulated flight utilized the 24 hour repeatable duty cycle which consisted of 8 hours of uninterrupted sleep, and 10 hours of on-duty time interspersed with 6 hours of off-duty time. The second and third flights utilized a 26 hour repeatable cycle which consisted of two separate 4 hour sleep periods and 11 hours of on-duty time interspersed with 7 hours of off-duty time and the sleep periods. A physical conditioning program prior to each flight and an inflight exercise program were utilized in order to insure high physical endurance at the end of each flight. An evaluation procedure was developed in order to consider any decrements in physical conditioning due to the sustained flight periods.

The results of the study indicate that no decrement in crew performance during any of the three simulated flights could be traced to sensory deprivation or confinement. In general, crew performance was excellent on most tasks and no general decrement in performance occurred. However, a number of procedural errors occurred during each of the flights, gradually diminishing between the first and third flights. These procedural errors are discussed in terms of lack of training, lack of display optimization, and lack of practice during the flight period on the more complex

tasks, i.e., lunar landing. Further, no gross medical or psychological effects were noted during any of the flights. The inflight exercise program used during each of the simulated flights proved to be capable of maintaining physical endurance while the 26 hour duty cycle was most preferred by the crew. The results reported also include crew comments on displays, controls, and general crew tasks.

The above results and the conclusions which may be drawn from this study are presented in detail within the body of the report.

I. Introduction

Current requirements of manned lunar flight place the burden of increased reliability of the system upon the crew. Further, the controlled lunar landing maneuver, itself, is conceptualized as a manual task with the crew in control. Any number of analytical and simulator studies have indicated the crew's capability in increasing reliability and performing these control tasks (Ref. 1), (Ref. 2), and (Ref. 3). However, one important argument utilized by proponents of unmanned systems concerns the ability of the crew to perform the lunar landing flight task after periods of 3 to 3-1/2 days within the spacecraft. Indeed, the argument may be extended to the entire gamut of crew performance after a sustained period within the spacecraft. These effects of long term space flight seem to center around a number of inherent factors of the lunar mission. They are as follows:

A. Reduced spatial volumes which might introduce a confinement situation to which the crew will react.

B. The long duration of the flight which might introduce an abnormal sensory environment to the crew and one to which they will probably not adequately adapt.

These above factors could then be considered as possible contributors to decrements in well-learned performance and skills. A number of questions are immediately raised as to the validity of the above conclusion. First, to what extent does the manned lunar spacecraft contain elements of reduced spatial volumes and reduced sensory inputs to the crew? Second, how extensive are these effects when they occur, and what form do they take? Third, what additional variables influence the acceptability of the sensory environment, i.e., what effect does crew experience, duty cycle, etc. have on tolerance to such stressful environments.

The lunar mission and system which may be considered a factor in crew performance is briefly described in the next few pages. A more detailed description of the simulator and mission utilized in the present study is presented later in this report. Time of flight to the moon would take 7 days or longer depending upon the length of time spent upon the lunar surface. The phases of the mission include liftoff, earth ascent, injection into an earth parking orbit, translunar insertion, a number of translunar midcourse corrections, attainment of lunar orbit, lunar deorbit, braking and terminal portions of the lunar landing, lunar ascent, attainment of lunar orbit, transearth insertion, a number of transearth midcourse corrections, re-entry, and earth landing. Further, two system modes are available for the landing operation. One mode would contain the phases described above and would constitute the landing of the main spacecraft upon the lunar surface. The second mode would constitute the landing of a small, one or two man excursion vehicle which would detach itself from the main vehicle

after crew transfer. The small excursion vehicle would then ascent from the lunar surface and rendezvous with the main spacecraft which was maintained in a lunar orbit. The main spacecraft would then return to earth after crew transfer.

The main three man spacecraft would contain approximately 400 cubic feet of usable space. This would include all available space for crew facilities, display systems, on-board equipment, etc. The small excursion vehicle for lunar landings would contain seating and restraint systems plus the display and control systems required for the landings and subsequent rendezvous. Its size, of course, would be dependent upon the choice of a one or two man vehicle as well as time spent on the lunar surface.

The crew tasks for the lunar missions may be conveniently divided into three general categories: flight control tasks, system monitoring and management tasks and navigational tasks. The manual flight control tasks may be considered as operating during all dynamic phases from earth ascent to lunar landing to re-entry. During most dynamic phases the crew will be required to maintain commanded attitude angles and maintain control over vehicle propulsion. During specific phases of the mission, i.e., the braking and terminal phase of lunar landing, the rate of descent and translational velocities must also be controlled within specific limits. Again by maintaining proper attitude control and by maintaining proper management of propulsion, these other parameters can be controlled.

The system monitoring and management tasks are primarily concerned with maintaining a range of tolerances within all subsystems, detection of malfunctions or marginal conditions within the various subsystems, and general troubleshooting and corrective maintenance. These tasks are performed almost continuously thoughout the entire mission. During time-critical thrusting periods (ie., re-entry) all pertinent subsystem parameters are monitored by one of the three crew members who are on duty at that particular time. At other times during the flight, the crew member on duty would perform monitoring tasks and periodically system management tasks. Once a malfunction or marginal condition has occurred within a particular subsystem, the crew would perform troubleshooting and corrective maintenance. The extent of the monitoring task within the excursion vehicle would be somewhat less since the time spent in this vehicle would be quite short.

The navigational tasks require the use of a sextant device to obtain star data, and the use of the obtained data to compute future course corrections, if required. The task requires the crew to gather information, as described above, and place the obtained data into a computer to obtain trajectory information.

Other tasks would also be required of the crew which are primarily of personal hygiene; food preparation, etc. The crew would also have open communication with the earth except on the dark side of the moon or during malfunction of the communications subsystem.

The description given above of a lunar spacecraft and its associated mission phases would suggest the possible existence of a confinement situation and a sensory reduced environment. However, the extent of the effect of these stresses on crew performance cannot be evaluated on the basis of the above description, since there is no finite formula for the amount of performance decrement obtained as a function of amount of spatial area or reduction of sensory input.

A review of the available literature on sensory deprivation and confinement indicated a multitude of studies had been performed on sensory deprivation, confinement, and associated variables. Examples of each type of study are presented in Appendix A. These studies are conveniently divided into five areas: clinical and anectodal data, basic studies in sensory deprivation and confinement, simulated manned space flight studies, duty cycle studies, and physiological studies. A summary of the literature review is, however, presented in the chapter.

Stress in a physiological sense is easily definable and its clinical signs measurable (Ref. 4). However, psychological stress or stress produced by a change in the psychological environment, such as sensory deprivation or confinement, is more difficult to define and its effects more difficult to quantitively measure. Further, with psychological stress a large range in individual differences is found between the various subjects in their tolerance to the stress.

The literature review indicated is that there has not been any studies, with realistic space flight tasks, and dynamic displays except for that reported by Titov (Ref. 26). However, this was the confinement of a single individual apparently without the many complex tasks of a lunar mission. Short training missions have also been performed by U.S. Astronauts (Ref. 44), (Ref. 45), and only two other studies utilized tasks and/or personnel which approached the true lunar mission (Ref. 24 and Ref. 27). There were many studies reviewed which appeared diverse and unsystematized and many of these studies utilized minimal numbers of subjects which appears to be an inherent difficulty in this type of research.

The anectodal literature was found difficult to use because of the intensity of stress described which is not contemplated in manned space flight except in an extreme emergency condition. The reports of medical patients also is difficult to apply because of the lack of knowledge of the specific contribution of the particular disease to the measured stress. The report of phenomena such as "break-off" experienced by high performance jet pilots must await further substantiation before it can be taken seriously.

The literature on the basic studies in reduced spatial environments and sensory reduction indicated the occurrence of many effects. Some of these were as follows:

1. Shifts in internal norms in the detection of stimuli.

2. Perceptual disturbances in visual motor coordination, shape perception, etc.

3. Inability to perceive relevant stimuli.

4. Loss of logical reasoning in complex tasks.

5. Personality changes and bizarre behavior.

6. Stimulus hunger

7. Possible loss in motivation.

Again, the applicability of these data becomes difficult due to the lack of subjects who are representative of probable lunar mission crews, and who are well motivated and experienced in handling emergencies. The second factor which makes the application of these data difficult is the drastic measures utilized to produce confinement and sensory reduction. As stated earlier, these appear quite unrealistic to future manned space flight conditions except during emergencies such as communication breakdown or death of two of the three crew members. Further, most of these studies considered the effects on individual subjects rather than on a well-trained group of subjects who perform as a group. The presence of more than one individual certainly introduces additional sensory information into the environment. The last factor which makes application of these data difficult is the lack of realistic dynamic tasks based upon actual trajectories of a space mission upon which to base decrements in performance. Most of the tasks utilized in the reviewed studies were simple psychomotor tasks quite different conceptually from those contemplated in the lunar mission (Ref. 46).

The reviewed studies on simulated space missions tend to indicate less bizarre behaviors and personality effects than those found in basic studies of confinement and sensory deprivation. Criticism can, again, be directed toward the choice of subjects and types of tasks utilized to evaluate the effects of the situation on performance. The internal arrangement of the simulators were unrealistic as to actual long term space flight missions. Motivation of the crews utilized appeared to be an important variable and directly related to the realism of the task. Further, the effects of the duty cycle utilized appeared to have as important an effect on performance as the confinement or sensory deprived environments.

The studies reported on the use of various duty cycles indicates that a shift in diurnal variation and adaptation does occur which does not apparently interfere with performance. Again, the type of task and the type of crew selected in the studies reviewed leaves much to be desired. It was also noted that physical exercise might be a means of reducing some of the effects of confinement noted in the studies.

The general lack of systematic data, as evidenced from the literature review as to the effects of confinement and sensory deprivation on crew performance during long term space missions, dictated the study to be presented in succeeding pages of this report. The purpose of this study was to systematically evaluate crew performance as a function of long term, realistic simulated flights. In order to accomplish this main goal of the study, a simulator and mission profile, similar to the lunar flight concept presented earlier in this chapter, was utilized. To meet the general purpose of the simulator, the following factors were included as part of the study:

1. The use of dynamic performance tasks which correspond to the flight control phases of a lunar mission.

2. The use of realistic representations of system and navigation tasks which correspond to lunar mission tasks.

3. The use of various duty cycles to evaluate their effects on task performance.

4. The use of various psychophysiological measures as indices of reaction or tolerance to stress.

Further, in order to make the evaluation of performance decrements during simulated flights as realistic as possible, the use of a sample population similar to the astronaut population was required. Also of importance is the use of lunar mission trajectories and time sequences which are realistic. This last point on realism should be emphasized. If the data obtained from this study are to be useful as to answering the question of performance decrements due to confinement or sensory deprivation, as much realism as possible must be injected into the study. This includes not only the crew composition, the flight trajectories, and the internal arrangement of the simulator, but also the crew tasks and operation procedures utilized in each simulated flight.

One additional factor must be introduced which is related to the general purpose of the study; crew task workload and task complexity. In order to specifically evaluate the effects of sensory deprivation and confinement on performance, it was deemed necessary to increase to the maximum, at least during the dynamic phases, the crew workload and the task complexity. Though this would be somewhat of a departure from

the realism of the mission simulation, (i.e., the complete capability of the crew would not be committed during the performance of any task in the event of an emergency) it was necessary to insure that whatever stress effects were noted were indeed based on complex behavior. Less complex monitoring tasks were also available for a comparative analysis.

Additional goals of this study which can be achieved in the course of such a realistic mission simulation concern the collection of data on information display requirements, cabin configuration, and the maintenance of physical endurance of the crew after prolonged simulated lunar flights.

General information concerning the ease of lunar landing with a main vehicle and an excursion vehicle was also programmed into the present study. The question raised concerned a possible difference in crew performance based upon the difference in vehicle dynamics between a main vehicle landing and excursion vehicle landings. Are the pilot tasks more difficult and are there any specific stress effects which are more pronounced in a one-man excursion vehicle as opposed to the main vehicle after the same period of simulated flight?

The study performed to achieve the above goals consisted of a pilot orientation, pilot training (including physical conditioning, medical evaluation, and task training), and collection of preflight baseline data phases spanning 12 weeks. Three simulated flights were conducted at the end of these phases. Two of these flights were of approximately 75 hours duration and the last flight was of approximately 168 hours duration. Two different duty cycles (a 24 hour and 26 hour) were used in the two 75 hour flights. On the basis of the results of these flights, the 26 hour duty cycle was chosen for the 168 hour flight. All crew members were NASA test pilots with extensive experience. Various display modifications were also made between the three flights.

The experimental variables, facilities description, crew training, and results are discussed in detail in the remainder of this report. It should be noted that this study should not be considered as a basis of design information but rather a basis upon which to perform future simulations which will utilize operational equipment and increased flight mechanics sophistication.

Further, the data presented in the tables and figures may not be as accurate as normally desired. This is due to the large mass of data collected and the short time for analysis. Therefore, care should be taken in making general interpretations of the raw data presented.

II. Description of Facilities

The facilities utilized in this program may conveniently be divided into the following areas; main vehicle simulator, excursion vehicle simulator, control room, and analog facilities. Each of the above will be discussed with sufficient detail to allow the reader to have an appreciation for the equipment utilized in the simulation.

A. Main Vehicle and Excursion Vehicle Simulators

Both simulators were housed in an air-conditioned room having dimensions of 50 x 31 x 16 feet, providing a total area of 1,500 square feet. The room was light tight and partially sound attenuated. During each flight the room was completely dark.

At periods of 4 hours, Martin and NASA personnel made a visual inspection of the crew through the simulator's one-way windows. During this inspection period, pertinent equipment was also checked to assure continued proper functioning.

1. Main Vehicle Simulator: Fig. 1 presents the external configuration of the main simulator. The main simulator was of a frame, stringer and aluminum skin construction. The external configuration consisted of a conical forebody with a half angle of 30°, a base diameter of 166 inches, and a hemisphere with a 17 inch radius at the apex. The aft bulkhead was a frustian of a flat cone with a base common to the forebody, a height of 17-1/2 feet and a minor diameter of 42 inches.

The main simulator was contained within its operating position by a structural cradle. The cradle in turn was vibration isolated and sound dampened from external disturbances by 5 Korfund vibro-isolators. Further, the main simulator was partially surrounded by a platform which allowed free movement around the simulator for observation purposes. The simulator contained six observation windows (one-way glass) for viewing the occupants during the flights. Ingress to the simulator was gained through a hatch located in the center of the aft bulkhead. Connected to this hatch was a 12 foot long enclosed tunnel which terminated at the excursion vehicle. This can be seen in Fig. 2. The main simulator could be isolated from the tunnel by closing the hatch door. The main simulator also enclosed an area of approximately 400 cubic feet.

The internal configuration of the main simulator was divided into the following areas: flight deck, sleeping area, off-duty area, toilet, a maintenance and response area, and galley. A description of each area is presented below:

a. Flight deck - The flight deck as illustrated in Fig. 3 consisted of a display-control panel, attitude control sticks, three seats, a prototype sextant, and a modified adding machine. The display-control panel extended across the full width of the simulator and provided for three crew positions.

Fig. 4 presents the display-control panel. Facing the foreward section of the simulator, the commander occupied the left position, the navigator the center position, and the engineer the right position. As can be seen in Fig. 4, the commander's position provided flight control capability for all dynamic phases of the lunar mission and subsequent return to earth. The displays consisted of the following: a 3-axis attitude indicator, attitude rate indicators, $\dot{h}$, velocity and altitude indicators. Further, a digital display for various mission phases was added prior to Flight III and presented, depending on the phase, ΔV, $\dot{h}$, or $\ddot{h}$ error information. (This digital display is not shown in Fig. 4). A cathode ray tube utilized as a flight director during various phases, clocks, timers, a radar altimeter, and lunar landing gear controls were also located on this panel. In addition, a throttle box located to the left of the commander provided throttle control. An abort handle, a boost, and re-entry sequence stepping switch for manned backup was also provided. (See Fig. 4A).

The navigator's panel contained a cathode ray tube, 3 separate attitude angle meters, attitude rate, velocity, and altitude indicators. This was a standby flight control area for emergency backup of the commander. Also included on this panel were clocks and timers, inertial platform controls, on-board computer controls, and communications controls. Directly above the navigator's position was the tri-sextant and a circular window which when illuminated revealed the starfield and associated planets. At both the commander's and navigator's positions were located 2 axis control sticks (pitch and roll) and yaw pedals. Activation of either stick was made by depressing a button at the top of the stick which illuminated a red light indicating

which stick was activated. Only one stick could be activated at a time with the commander's stick taking precedence. Further, each stick could be stored within the arm of the seat and was out of the way except when in use. The panel area between the commander and navigator contained displays common for both positions. These displays included propulsion and stabilization controls.

The engineer's panel contained displays which presented quantitative status of the various on-board systems. These displays included information concerning the environmental control system, electric power system, radiation status, meteorite impact indicators, propulsion system status, etc.

Across the top of the display system panel were boost, re-entry, and earth landing sequence indicator lights. The sequence lights presented indications whether given critical events, during the boost, re-entry and landing phases have occurred successfully. Also located at the top of the panel were master malfunction warning indicators. These malfunction warning lights were either green, amber, or flashing red. The green light indicated the system was in a "go" condition and operational. The amber light indicated the system was marginal, and the flashing red indicated a malfunction had occurred. Auditory signals occurred in conjunction with a malfunction, an abort, radiation accumulation of one rem or more, and meteorite hits. The abort auditory signal was added after Flight I and the radiation and meteorite auditory signals were added after Flight II. To the right of the engineer's seat was a converted adding machine which was utilized to enter star data obtained from operation of the sextant.

The flight panel was color coded to demarcate the various discrete functions embodied in the panel.

The display-control system attempted to provide the following operational aspects to the simulation:

1. All prime control tasks could be performed from either the commander's or navigator's position. This provided an emergency backup to the commander in the event of an emergency.

2. Critical and frequently used flight displays were placed between the commander and navigator allowing sharing and savings in panel space.

3. Task sharing, display and data checking operations, and continual cross-checking could be achieved between the various duty positions due to the adjacent seating of the three crew members. Further, each crew member could monitor the performance of the other two.

4. The single panel arrangement permitted one crew member to effectively monitor all on-board systems from the center position during the coast periods.

5. A single position for malfunction location indicators allowed for a "quick look" as to system status.

It should be noted that this display system and its associated concepts were not previously evaluated by pilot personnel prior to the present experimental studies. Therefore, the proper positioning of critical displays, scan pattern, etc. were unknown qualities.

The three seats mentioned earlier have a configuration similar to a high-backed arm chair. However, only a small range of adjustment of inclination of the backs of the left and right seats was possible. The center seat was mounted on tracks and could be pushed forward and back. As previously stated, the sextant was mounted above and slightly forward of the navigator's seat. In order to use the sextant, the crew-member pushed the center seat back, and stood on a folding platform which was attached to the bottom of the seat. With the control sticks stored the right arm support of the commander's seat and the left arm support of the engineer's could be folded back and locked to the bulkhead at the rear of the seats. Access to the flight deck from below was accomplished by pushing the center seat back and by locking the arm supports to the bulkhead.

b. Sleeping Area - This area, which was large enough for one crew member at a time, was below the flight deck and extended almost the full length of the left side of the main simulator. The area contained its own illumination and had a 3 inch thick, 65 inch long mattress supported by a horizontal platform. Heavy curtains separated the sleeping area from the other areas of the simulator. Additional sound attenuation was added after Flight II.

c. Off-Duty Area - The off-duty area, which was located in the lower right rear corner of the simulator opposite the sleeping area is presented in Fig. 5. This area consisted of a chair, a refrigerator, and a music system. The lounging-type chair was inclined at a fixed position for relaxation. The refrigerator, approximately 3 cubic feet, was to the right of the chair. Adjacent to the chair was a panel for the selection of taped music from the control room. The music could only be heard by means of a headset. An extension of the music system was made by the crew and allowed the on-duty crew member to also listen to music while listening to the control room messages.

d. Toilet - The toilet, which was supplied by American Machine & Foundry for purposes of this simulation, was located above the sleeping area, and opposite the off-duty area. The toilet was of the feces-freezing type, and was not used for urination since all urine was collected and analyzed. The crew urinated into leak-proof containers, which were dropped into a chute at the rear of the toilet. The containers then dropped into a freezing unit outside of the vehicle. This chute can be seen in Fig. 1.

e. Galley - The galley was situated above the off-duty area in the upper-right rear corner of the vehicle. Access to the galley was by means of a platform which was accessible from the off-duty area. The galley area contained a water supply, two electric liquid heaters, shelves, and a fold-down counter and seat. A small electric oven, for heating frozen or prepared foods was located below the sleeping area opposite the off-duty couch.

f. Maintenance-Response Area - Located close to the off-duty area was a panel for simulating trouble-shooting and maintenance, and a panel for performing behavior response tasks. The maintenance panel consisted of a series of rotary switches, jacks and plugs which had to be positioned appropriately in order to simulate troubleshooting for malfunctioned subsystem components. The response panel was used for a reaction time task, a time estimation task, and during the first flight, a memory (for digits) task.

2. Excursion Vehicle Simulator: The one-man excursion vehicle simulator can be seen in Fig. 6. The external configuration of this simulator was similar to that of a cockpit section of a one-man aircraft. This simulator was supported on a platform at the end of the aforementioned tunnel (Fig. 2). After the main hatch located in the center of the tunnel had been secured, the only access to the excursion vehicle was from the main vehicle through the tunnel. The excursion vehicle had an opaque screen which separated it from the tunnel when occupied.

The forward section of the excursion vehicle had a transparent window which faced a wall. Upon the wall was projected a starfield utilized during the rendezvous phase of each flight. The rendezvous equipment, a servo projector system controlled by the analogue which presented a starfield and blinking light, was mounted on a tower approximately 8 feet to the rear and above the excursion vehicle (Fig. 7). The excursion vehicle also contained a one-way window for observation of the crew.

The excursion vehicle simulator display-control panel was a wrap-around panel extending across the front of the simulator (Fig. 8). The displayed information consisted of a two-axis attitude indicator, a yaw meter, attitude rate meters, altitude and velocity meters, a 24-hour clock, and a total elapsed mission timer. Also included was a cathode ray tube which was utilized as a flight director, a digital meter (added prior to Flight III) which displayed ΔV or $\dot{h}$ depending on the mission phase, and system status warning lights. The control system consisted of throttle controls and two control sticks. Attitude control was accomplished by means of a 2-axis rate command control stick (pitch and roll) and yaw pedals. A translation stick located at the pilot's left hand was used during the rendezvous phase. It should be noted that a yaw bias existed in both the main and excursion vehicle control system due to the mechanical design of the equipment. No correction was introduced during the course of the study because of time and financial limitations.

B. Control Room

The control room, as seen in Fig. 9, had a floor area of approximately 435 sq. feet and was located adjacent to the simulator room. The control room coordinated the simulation and the inputs to the various simulators, including those from the analogue computer facility. The outputs of the crew were received in both the control room and analogue facility during thrusting phases.

The major items of equipment in the control room were as follows:

a. Twelve control consoles
b. Two closed circuit television monitors
c. Intercommunication system
d. Three tape recorders
e. Closed circuit television data system

f. Esterline Angus event recorder
g. 24-Hour clock

The control room consoles presented in Fig. 9 contained the controls from which the inputs to the simulator panel displays and indicators were controlled. The consoles also contained panel lights which indicated the positions in which the crew has set the display panel switches and controls. In addition, one of the consoles contained meters which indicate pitch, roll, and yaw attitude angles and rates, velocity, altitude and h during manual flight control and thrusting phases of the mission. However, these simulator displays were controlled by the analogue facility. Prior to the third flight, a meter showing the last 20% of fuel remaining, was installed. In general, the management of the control room consoles was dictated by detailed Control Room Procedures which indicated the required actions of the control room personnel as a function of mission time.

By means of cameras located in the main vehicle, two closed circuit television monitors were used to monitor the crew at any two of four positions in the main vehicle at any given time. The four positions monitored were the three duty stations on the flight deck and the off-duty area. No crew monitoring device for the excursion vehicle was available from the control room.

The intercom system provided communications between crew members and the control room. Most conversations among crew members could be heard in the control room through 12 microphones located in the different areas of the main simulator, tunnel, and excursion vehicle simulator.

Two of the three tape recorders were used to record communications between the crew and the control room, as well as conversations among crew members themselves. The third tape recorder was used to play music, which was received by the main vehicle simulator as previously discussed. Approximately 10 music tapes were available and could be requested by the crew via a buzzer system.

Certain types of data and information were provided to the crew by means of the closed circuit television data system. These were star fix data, guidance data, and midcourse correction data. Before the data was transmitted to the crew it was checked for accuracy on a television tube. The Esterline Angus recorder was used to record the activation and deactivation of the throttles, as well as the boost, re-entry and landing manual sequencing.

The 24-hour electric clock, (which was mounted above the two center consoles) was used for determining both standard and Greenwich Mean Time. This clock was synchronized with the clock at the analogue computer facility and the clocks in the main and excursion vehicle simulators.

The control room crew consisted of a Flight Director, a Capsule Communicator and two technicians. The Flight Director (a Martin Company employee) was responsible for coordinating the activities of the technicians operating the consoles, and for making routine decisions. The Capsule Communicator (a NASA employee) was responsible for communicating with the crew; and the two technicians were responsible for operating the consoles. Three complete control room crews were utilized, one for each 8 hour shift during a 24 hour period. Sufficient overlap was provided between crews for the relay of pertinent information.

C. Training and Flight Manuals

In order to train the crew and control room personnel in the mission concept, operation of the equipment, and flight time history, a group of training and flight manuals were developed. The manuals were as follows:

1. Crew-equipment operating procedures.
2. Description of the simulated system.
3. Flight plans for each of the three flights.
4. Malfunction detection procedures.
5. Control room operating manual and time history.

From the first four manuals mentioned above, the crew developed an inflight check list which contained sequential operating steps for each mission phase. This check list was revised after Flights I and II by the crew. The control room manual presented a time sequence of changing simulator displays from the control room. This included the type and time of a malfunction, engine temperatures and pressures, etc. Sample pages of the procedures and flight plan manuals are presented in Appendix B.

Prior to each flight and during practice trials on each dynamic phase an analogue trial log was kept. This log contained trial number, date, phase, pilot, and pertinent performance data. During each flight a control room log was maintained noting pertinent events during the flight.

D. Analogue Facilities

Fig. 10 presents a view of the analogue facilities utilized in the present study. These facilities were located in a central computing room approximately 1500 feet from the simulators and control room. A tie-line bridged this distance providing input and output signals from the simulator and analogue room respectively.

A total of four computers were used to simulate the many flight phases of this mission. There were three REAC C-400 computers and one EAI 231R. In addition to the computers, four REAC C-109, used as signal conditioners, were required along with several relay chassis and specially built switching consoles. A combined total of 262 operational amplifiers were used by these machines. The allocation of the machines showing amplifier,

multiplier, resolver, etc., usage is shown in Table 1. Note that two patchboards were wired for one of the C-400's (Machine 4) and the 231R corresponding to different flight phases.

An important variable in maintaining the realism of the present simulation was the reliability of the facilities utilized. Throughout the three experimental flights a total of only 115 minutes was lost through unplanned malfunctions or equipment failures. In every case except one, the malfunction was repaired and the mission proceeded without undue disturbance to the crew. During Flight I, the excursion vehicle CRT failed during one of the rendezvous phases. It was repaired before the next rendezvous. The only instance of an unrepaired malfunction occurred in Flight III. The servoed rendezvous projector failed during the first excursion landing and could not be repaired. Therefore, subsequent rendezvous phases were made without use of the visual starfield.

Table 1

Analogue Equipment Utilization

Flight Phase	Machine	Sum-mers	Inte-grators	Invertors	Multipliers Servo	Multipliers Elec.	Resolvers Servo	Resolvers Elec.	Pots.	Function Generators
Earth Ascent	231R	52	12	18	3	12	0	0	59	3-1/2
Earth Orbit Trans-Lunar Insertion	4 (C-400)	12	12	14	2	0	1	0	63	0
Translunar Coast Mid-Course Corrections All Lunar Phases Including: Orbit Insert., Orbit, De-orbit, Landing and Ascent Trans-Earth Insertion and Coast	5 & 6 (C-400's)	24	24	31	5	2	2	0	137	6
Rendezvous	4 (C-400)	12	12	16	2	0	0	0	40	0
Re-entry	231R	61	13	14	2	10	0	1	43	2
Signal Conditioners (C-100's)	9	7	0	4	0	0	0	0	10	0
	10	10	0	6	0	0	0	0	6	0
	11	3	2	5	0	0	0	0	14	0
	12	9	0	5	0	0	2	0	14	0

III. Experimental Variables

The specific design of studies to be reported and the various variables measured were mainly predicated upon a comparison of preflight performance with either inflight or postflight performance of the crew. This dictated fairly extensive training of the crew prior to each simulator flight as well as the collection of preflight baseline data in order to have valid measures.

A. Variables Measured

The following are the specific variables measured and data utilized in the evaluation of crew performance:

Variable 1. Flight Control Tasks - Preflight baseline and inflight data were collected on all dynamic flight control phases. This included earth ascent, translunar insertion, three translunar midcourse corrections, lunar orbit insertion, lunar deorbit, terminal and braking, lunar ascent and rendezvous. For Flight III data were also collected on transearth insertion, three transearth midcourse corrections and earth reentry. Also collected as part of the flight control tasks were the crew's performance on throttle controls and backup booster sequencing during various phases. The measure utilized was time of engine cutoff or time of sequencing. A more detailed description of the pilot tasks and the simulated dynamics are presented later in this report. Table 2 presents the specific measures taken during each of the flight control phases upon which an evaluation of pilot performance was made. It should be noted that the fuel measure in Phases 6 and 8 of Table 2 was computed as follows:

The $\int T\,dt$ was recorded. Since $\int T\,dt = I_{sp} \int \dot{w}\,dt$, the $\int \frac{T\,dt}{I_{sp}} = \dot{w}\,dt$. The fuel measure then is $\int \dot{w}\,dt$ since I_{sp} is known.

Variable 2. System Tasks - Preflight and inflight data were collected on each of three flights on the accuracy and average time for performing systems and log checks. The systems check was a procedure for checking onboard systems while the log check was

Table 2

Specific Measures Utilized During Dynamic Flight Control Phases

Phase	Measures
1. Earth ascent	θ, ψ, ϕ $\int\sqrt{\theta_E^2 + \psi_E^2 + \phi_E^2}\ dt$
2. Translunar Insertion	ΔV and $\int\sqrt{\theta_E^2 + \psi_E^2 + \phi_E^2}\ dt$
3. Midcourse corrections (translunar)	ΔV
4. Lunar orbit insertion	ΔV and $\int\sqrt{\theta_E^2 + \psi_E^2 + \phi_E^2}\ dt$
5. Lunar deorbit	ΔV and $\int\sqrt{\theta_E^2 + \psi_E^2 + \phi_E^2}\ dt$
6. Lunar landing (terminal & braking)	$\dot{x}$, $\dot{h}$, $\dot{\psi}$, $\dot{\theta}$, $\dot{\phi}$, θ_E, ψ_E, ϕ_E, Vf, fuel ($\int\dot{w}\ dt$)
7. Lunar ascent	ΔV and $\int\sqrt{\theta_E^2 + \psi_E^2 + \phi_E^2}\ dt$
8. Rendezvous	x, $\dot{x}$, y, $\dot{y}$, z, $\dot{z}$
9. Transearth insertion	ΔV and $\int\sqrt{\theta_E^2 + \psi_E^2 + \phi_E^2}\ dt$
10. Transearth midcourse	ΔV
11. Re-entry	$\int\sqrt{\theta_E^2 + \psi_E^2 + \phi_E^2}\ dt\ \dot{h}$ and $\int$ Vhe

utilized for the periodic description of detailed aspects of the onboard systems.

Variable 3. Detection of Malfunctions - Two types of malfunctions were utilized during each flight. Type A required only an adjustment be made while type B required a troubleshooting task at the maintenance panel. On type A malfunction detection, the measure utilized was a comparison between the crew adjustment procedure and the previously instructed adjustment procedure. On type B malfunction detection, the crew's performance was compared with an optimum mathematical strategy.

Variable 4. Navigational Tasks - The crew's performance in performing navigational tasks during flight was compared with baseline data in terms of accuracy of performing the star measurements.

Variable 5. Behavioral Response Tasks - Two behavioral response tasks, time estimation and reaction time, were performed by the crew during each of the flights. A comparison was made of latency of response between baseline and flight data.

Variable 6. Duty Cycle, Displays and Internal Configuration - Subjective reports of the crew members and ground crew were utilized to evaluate the usability of the duty cycle, displays and internal configuration of the simulator and mission.

Variable 7. Physical Condition - The physical conditioning of the crew at the end of each flight was compared with baseline performance. The comparative measures consisted of the number of repetitions of specific exercises and time to perform specific exercise. Subjective reports of the crew concerning the inflight exercise regime were also utilized.

Variable 8. 17-Hydroxycorticosteroid Analyses - The excretion of 17-hydroxycorticosteroids during each flight was compared with at least 48 hours of preflight baseline data. The measurement utilized was milligrams per hour of excreted corticoids.

Variable 9. Psychological Evaluation - Crew behavior after Flight I and III was compared with baseline performance data collected prior to Flight I. The Rorschach projective technique plus the psychiatric

interview were utilized as measurement devices.

Variable 10. Medical Evaluation - The medical evaluation procedure consisted of a thorough analysis of body systems prior to Flight I plus general examinations immediately prior and after each flight. The Harvard Step Test was administered during the initial examination and prior to and immediately after Flight III.

Variable 11. Analysis of Taped Data - All crew conversations were taped between the crew members and between the simulator and the control room. Analyses of these data for any significant trend or change in verbal responses during various mission phases were made.

Variable 12. General Physiological Data - During each flight blood pressure measurements were taken on each crew member every 6-8 hours. These data were analyzed for any trend as a function of mission phase. Subjective comments concerning the diet in terms of quality of diet and caloric value were also collected.

These 12 variables with their various evaluative measure constitute the data available from the present study. Table 3 presents a categorization of these variables into various pertinent areas. As can be seen from this table, useful data was obtained in the areas of crew performance, general systems data and crew reaction to the environment. Before presenting the detailed design of each flight, consider the importance of each of these variables to the general purpose of the study which was presented in a previous chapter.

Variable 1. This variable provides a measure of crew performance with complex tasks after varying periods in the simulator environment (i.e., earth ascent, lunar landing and re-entry). Since these tasks are generated via analog computers, there also exists display-control feedback which increases the realism of the variable. Any performance decrement due to confinement or sensory deprivation should appear in these tasks.

Variables 2 and 3. These variables provide an index to the general problem of crew monitoring during long-term spaceflight. Since the literature review indicated that this behavior is most liable to confinement or sensory deprived environments, a realistic set of monitoring procedures should then indicate performance decrements.

Table 3

Category of Variables

Crew Performance Within the System	General Systems Data	Crew Reaction to Environment
Variable 1 - Flight Control Task	Variable 1 - Flight Control Tasks	Variable 1 - Flight Control Tasks
Variable 2 - Systems Task	Variable 2 - Systems Tasks	Variable 2 - Systems Tasks
Variable 3 - Detection of Malfunctions	Variable 3 - Display and internal configuration	Variable 3 - Detection of Malfunctions
Variable 4 - Navigational Tasks	Variable 7 - Physical condition	Variable 4 - Navigational Tasks
Variable 5 - Duty Cycle		Variable 5 - Behavioral Response Tasks
Variable 6 - Physical Condition		Variable 6 - Duty Cycle
		Variable 7 - Physical Condition
		Variable 8 - Cortiosteroid analysis
		Variable 9 - Psychological evaluation
		Variable 10 - Medical evaluation
		Variable 11 - Analysis of taped data
		Variable 12 - General physiological data

Variables 3 and 4. These variables provide an index to the performance of the crew under the supposed stress with less complex tasks than the flight control tasks, but tasks pertinent and related to adequate system performance.

Variable 5. This variable is the only task performed by the crew which is not related to system function. It consisted of a reaction time test and a time estimation test. Both of these behaviors, according to the literature review, are liable to confinement and sensory deprivation stress.

Variables 6 and 7. These variables, dependent upon their utility, contribute to high crew performance within the system. The proper manipulation of these variables could further enhance or alleviate any effects of confinement or sensory deprivation stress.

Variables 8, 9, 10, 11 and 12. These variables are primarily concerned with the crew reaction psychologically and physiologically to the environment. The question raised is as follows: Are any of these indices sufficiently changed from normal to be indicative of expected crew difficulty?

B. Design of Each Flight

The following is a detail design of each flight with any equipment changes made between the flight. Special training of the crew will be discussed later in this report.

1. Flight I

Flight I was designed as a 75 hour mission and began at 1030 (EST) on 5 June 1962. Each crew member made a lunar landing with the main vehicle and a lunar ascent. Further, after a six hour period in lunar orbit, each crew member then made a landing with the excursion vehicle, a lunar ascent, and then rendezvoused with the main vehicle in lunar orbit. The flight terminated at this point. An aborted lunar landing occurred once with the main vehicle and once with the excursion vehicle during the braking phase of lunar landing. Further, a planned communication loss occurred during one of the excursion vehicle flights after the vehicle was on the lunar surface. This communication loss eliminated lunar ascent countdown time provided by

the control room and communication aid from the main vehicle. This placed the burden of proper ascent timing and performance solely on the pilot. Communication blackouts also occurred when the vehicle was on the backside of the moon as expected in an actual mission.

Six subsystems malfunctions were given to the crew which required either adjustment or troubleshooting maintenance be performed. Urine collection was initiated 49 hours prior to liftoff, and was continued throughout the flight at approximately 4 hour intervals except during sleep periods. The inflight exercise program was performed at the crew's discretion and blood pressures were collected approximately every 8 hours during the flight. One day's supply of food was placed in the vehicle at launch and a new food supply was rendezvoused during each succeeding day of flight. The diet was an 1800 Cal. diet. A physical conditioning evaluation test was also given to the crew prior to Flight I.

The duty cycle utilized by the crew was a 24 hour cycle, which had 8 hours of uninterrupted sleep, approximately 10 hours of on-duty time, and 6 hours of off-duty time interspersed with on-duty hours. The behavioral response tasks consisted of 3 tests during Flight I. These were immediate memory, reaction time and time estimation. A total of 25 minutes of each 24 hours was spent by each crew member in the performance of these tasks.

The various mission phases and other pertinent data of Flight I from June 5 to June 8 are presented as follows:

a. Breakfast and Medical Check
b. Prelaunch Phase
c. Liftoff
d. Ascent to earth parking orbit
e. Translunar insertion
f. Translunar coast
g. Three translunar corrections
h. Lunar orbit insertion
i. Lunar orbit
j. Three main vehicle landings, one performed by each crew member. Main vehicle landing No. 1 was an abort at 3000 feet due to electric power failure. Other landings completed.
k. Two lunar ascents
l. Lunar orbit duty cycle (5.5 hours)

m. Three excursion vehicle landings, one performed by each crew member. The second excursion vehicle landing was an abort, but rendezvous was completed.
n. Two lunar ascents
o. Three rendezvous
p. The third excursion vehicle at lunar touchdown was given a communication failure and subsequent steps (lunar ascent and rendezvous) were performed without communication.
q. The flight was terminated at the end of the third rendezvous.
r. Crew debriefing
s. Medical, psychological, physical conditioning evaluation.

2. Flight II

The second flight, which began on 19 June 1962 at 1030 (EST), was also a 75 hour flight. It differed from the first flight in a number of ways.

a. A different duty cycle was utilized. This cycle was a 26 hour cycle in which the sleep periods were only 4 hours duration with on-duty and off-duty periods between each sleep period. The specific aspects of this cycle will be discussed later in this report.

b. Two of the crew members had taken part in Flight I while the third had not, and served only as an observer.

c. Only two tests, time estimation and reaction time, were given as part of the behavioral response tasks.

d. Only one abort occurred during the main vehicle lunar landings. All other lunar landings with both the main vehicle and excursion vehicle were completed.

e. The inflight exercise program was performed for five minutes during each off-duty period for the first 45 hours and every other off-duty period for the remainder of the flight.

f. An auditory warning signal was added for malfunction and abort situations.

g. Noise was added to the lunar injection and midcourse phases.

h. The yaw needle on the 3-axis ball was activated for all phases.

i. The midcourse display scaled ΔV was changed from 0 - 100 fps to 0 - 40 fps with the elimination of a benchmark on the display.

j. No psychological or psychiatric evaluation was made immediately before or after Flight II.

In all other respects Flight II was similar to Flight I.

3. Flight III

Flight III, which began at 1030 (EST) on 6 July 1962, differed from Flight I and/or Flight II in the following ways:

a. Flight III was 163.5 hours in duration.

b. The following flight phases were added to the mission:

(1) Transearth insertion
(2) Three transearth corrections
(3) Re-entry

c. Three earth re-entries were performed, one by each crew member.

d. The inflight exercise program was performed every other duty period.

e. Instead of a physical exercise evaluation prior to and immediately after Flight III, the Harvard Step Test was given to each crew member.

f. The 26 hour duty cycle utilized in Flight II was used in Flight III.

g. The caloric intake was lowered to 1500 calories.

h. Urine collection for baseline was undertaken approximately 72 hours prior to Flight III.

i. A digital readout on obtained ΔV and $\dot{h}$ was added to the display panel in both the main vehicle and the excursion vehicle.

j. An audio signal was provided for meterorite hits and the accumulation of radiation at levels of 1 rem or more.

k. A fuel meter was added presenting the last 20 per cent of fuel remaining during lunar landing.

l. A medical, psychological and psychiatric examination was conducted after Flight III.

m. One abort with the main vehicle was conducted during Flight III.

n. Twelve malfunctions which required either adjustment or troubleshooting maintenance were given during Flight III.

IV. Description of Crew & Crew Training

One of the major questions raised by the literature review presented in Chapter I of this report was the effect of subject background and experience on tolerance to sensory deprivation or confinement. The simulated flights and equipment as previously described did provide an environment which was somewhat different than normal and contained components of both confinement and sensory deprivation. Therefore, one goal of the study was to utilize subjects who had sufficient flight experience and background to withstand any stress inherent in this simulation. Further, in order to generalize from the present simulation crew performance to the actual long term flight performance of the crew, a population similar to the astronaut population was used. Another goal of the study, that was also indicated from the literature review, was the importance of continued high motivation throughout the program. It was believed that aside from the general high interest of the crew in this study, their actual participation in the design of the study and in aiding readying the simulator for flights would aid in maintaining high motivation. This should be considered in evaluating the description of the training program.

This chapter will present a brief description of the crew members, the pre-flight crew evaluation, and crew training.

A. Crew Description

Four crew members were assigned by NASA to participate in the present study. Since only three crew members were required for each flight, the fourth crew member served as capsule communicator with other resident NASA personnel. The four crew members provided by NASA were all experimental test pilots with extensive flight experience and each held a degree in engineering. The pilots had an average of 4500 hours of reciprocating and jet engine time. Further, they had flown an average of 40 different types of aircraft, had extensive analog simulation experience, had participated in centrifuge tests, etc.

The age range was between 31 and 38 years of age with two pilots being at each end of this age distribution. All the crew members were of good health and had no known disabilities. In succeeding chapters of this report, the pilots will be designated as Pilot A, Pilot B, Pilot C and Pilot D. However, Pilot D participated only as an observer in one of the flights and therefore, his performance will not be reported. The following indicates which pilots participated in each of the three flights and their assigned positions:

1. Flight I

   a. Pilot A - Engineer
   b. Pilot B - Navigator
   c. Pilot C - Commander

2. Flight II

   a. Pilot A - Commander
   b. Pilot B - Engineer
   c. Pilot D - Navigator

3. Flight III

   a. Pilot A - Navigator
   b. Pilot B - Commander
   c. Pilot C - Engineer

B. Crew Training & Evaluation

Crew training and evaluation during the program was divided into the following:

1. Knowledge and practice of simulator operating procedures.

2. Knowledge and practice of the simulator dynamic flight control tasks.

3 Collection of baseline (pre-experimental) data on all appropriate tasks.

4. Physical conditioning.

5. Medical and psychological evaluation.

It should be noted that in the present studies, the crew played an integral part in the preparation of the simulator and tasks for each flight. Except for the occurrence of planned malfunctions, abort situations, and the results of the psychological tests, the crew was completely knowledgeable and informed of all aspects of the study.

1. Crew Orientation - The initial introduction of the program to the crew was a 5 day orientation meeting held shortly after the program was initiated. The orientation meeting consisted of an introduction as to the purpose of the study, lectures on the various systems which were simulated, the presentation of simulator operating procedures, and the medical and psychological evaluation. Further, during this meeting, the duty cycle, the Flight I mission plan, and the physical conditioning program were presented.

   After this initial meeting, the crew spent approximately 3 days at the Martin facility and began the physical conditioning and procedures review at their home base.

Approximately three weeks after the initial meeting, a 5 day procedures review meeting was held with the crew. The purpose of this meeting was the following:

a. Review and correct crew simulator procedures.

b. Present and discuss the simulator malfunction detection procedures.

c. To present revised flight plan and duty cycle for Flight I.

d. To familiarize the crew with the flight display and allow for practice with the rendezvous phase.

e. To supervise crew exercise and present the inflight exercise program.

After 21 May 1962 the crew members were present on almost a full time basis.

2. Flight Control Practice & Baseline - Tables 4, 5, and 6 present the number of trials each crew member received on each phase prior to each flight. Inspection of these tables indicates a predominance of practice and baseline trials prior to Flight I as compared to Flights II and III. This is due to initial acquisition of the skills required to perform these complex tasks. The practice and baseline trials prior to Flights II and III then were predominantly concerned with peaking and maintaining proficiency and with learning different dynamic or displays which were changed prior to Flights II or III. Observation of these tables further indicates that for each flight one of the crew members received more training than the other two. This was not as completely the case in Flight I as in the other two flights. This situation existed because the commander in each particular flight was the only individual who performed earth ascent, translunar insertion, lunar orbit insertion, and in Flight III, transearth insertion. Inspection of Table 7 indicates that all crew members received approximately equal training. However, there were numerous additional trials not considered as practice but which were concerned with checking-out each phase. The majority of these trials were performed by Pilots A and B. These trials certainly contributed to additional training of Pilots A and B.

Table 7 also indicated that the major area of training was in the braking and terminal phases for both simulators (a total of 145 trials). This was due to the fairly complex nature of the tasks involved. Most of the trials presented in the above tables were not baseline data but were practice trials. However, for each phase prior to each flight at least 1 to 2 baseline trials were obtained. The exception existing in the transearth midcourse phase and in the lunar descent phase with the excursion vehicle simulator. Insufficient time made the attainment of these data impossible.

As part of practice on the flight control tasks, practice on simulator operating procedures also occurred, however again due to time limitations, these were not stressed. The crew continuously revised their inflight checklist to confirm with any procedural changes.

3. Navigational Practice & Baseline - Practice and baseline data were collected on crew performance using the trisextant and star slides. Prior to Flight I the crew members attended a lecture on the concept of navigation to be used for the simulation and participated in a 2 hour familiarization with the sextant. Each crew member was then given 2 readings on each of 10 slides to be utilized in the first simulation. Prior to Flight II the crew was given an additional trial on each slide and prior to Flight III, all three crew members were each given practice on two slides.

4. Physical Conditioning - As stated earlier in Chapter I, there existed a possibility of reducing any performance or physical effects of long term confinement by having the crew physically conditioned prior to the flight and to maintain their physical condition during each flight. In order to accomplish these goals, it was believed necessary to utilize a professional athletic trainer. This assured the program of having an adequate background of a variety of physical exercises plus considerable knowledge as to proper evaluation of the physical condition of the crew prior, during, and after each flight. For this reason a professional physical therapist participated in this program and designed the various exercises as well as supervised the evaluation of the crew in this area.

The physical conditioning program as originally conceived was divided into three distinct areas. These are as follows:

Table 4A
Number of Trials on Dynamic Flight Control Tasks
for Flight I on the Main Vehicle Simulator

Crew Member	Earth Ascent	Translunar Insertion	Midcourse	Lunar Orbit Insertion	Lunar Deorbit	Braking & Terminal	Lunar Ascent & Insertion	Abort	Total
Pilot A	5	3	5	4	--	23	9	2	51
Pilot B	7	2	4	2	--	7	4	3	29
Pilot C	13	10	1	2	--	18	5	2	51
Total	25	15	10	8	0	48	18	7	131

Table 4B
Number of Trials on Dynamic Flight Control Tasks
for Flight I on the Excursion Vehicle Simulator

Crew Member	Lunar Deorbit	Braking & Terminal	Lunar Ascent	Rendezvous	Abort	Total
Pilot A	--	15	2	11	2	30
Pilot B	--	21	6	10	3	40
Pilot C	--	21	2	4	6	33
Total	0	57	10	25	11	103

Table 5A

Number of Trials on Dynamic Flight Control Tasks
for Flight II on the Main Vehicle Simulator

Crew Member	Earth Ascent	Translunar Injection	Midcourse	Lunar Orbit Insertion	Lunar Deorbit	Braking & Terminal	Lunar Ascent & Insertion	Abort	Total
Pilot A	3	5	4	4	4	4	0	2	26
Pilot B	0	0	4	0	4	6	1	3	18
Total	3	5	8	4	8	10	1	5	44

Table 5B

Number of Trials on Dynamic Flight Control Tasks
for Flight II on the Excursion Vehicle Simulator

Crew Member	Lunar Deorbit	Braking & Terminal	Lunar Ascent	Rendezvous	Abort	Total
Pilot A	-	3	3	0	2	8
Pilot B	-	4	4	1	2	11
Total	0	7	7	1	4	19

Table 6A

Number of Trials on Dynamic Flight Control Tasks

for Flight III on the Main Vehicle Simulator

Crew Member	Earth Ascent	Translunar Insertion	Midcourse	Lunar Orbit Insertion	Lunar Deorbit	Braking & Terminal	Lunar Ascent & Insertion	Abort
Pilot A	-	-	-	-	-	3	3	1
Pilot B	2	2	3	2	-	3	3	-
Pilot C	-	-	3	-	-	3	3	-
Total	2	2	6	2	0	9	9	1

Table 6A (cont'd)

Crew Member	Transearth Insertion	Transearth Midcourse	Re-entry & Landing	Total
Pilot A	--	--	6	13
Pilot B	2	--	8	25
Pilot C	--	--	12	21
Total	2	0	26	59

Table 6B

Number of Trials on Dynamic Flight Control Tasks

for Flight III on the Excursion Vehicle Simulator

Crew Member	Lunar Deorbit	Braking & Terminal	Lunar Ascent	Rendezvous	Abort	Total
Pilot A	--	7	2	3	--	12
Pilot B	--	3	2	2	1	8
Pilot C	0	14	2	3	1	20
Total	0	14	6	8	2	40

Table 7

Total Number of Trials on All Phases for All Pilots

Crew Member	MAIN VEHICLE							
	Earth Ascent	Translunar Insertion	Translunar Midcourse	Lunar Orbit Insertion	Lunar Deorbit	Braking & Terminal	Lunar Ascent & Insertion	Abort
Pilot A	8	8	9	8	4	30	12	5
Pilot B	9	4	11	4	4	16	8	6
Pilot C	13	10	12	4	-	21	8	2
Total	30	22	32	16	8	67	28	13

Table 7 (Cont'd)

Total Number of Trials on All Phases for all Pilots

Crew Member	MAIN VEHICLE (Cont'd)			EXCURSION VEHICLE					
	Transearth Insertion	Transearth Midcourse	Re-entry & Landing	Lunar Deorbit	Braking & Terminal	Lunar Ascent	Rendezvous	Abort	Total
Pilot A	--	--	6	--	25	7	14	4	140
Pilot B	2	--	8	--	28	12	13	6	131
Pilot C	--	--	12	--	25	4	7	7	125
Total	2	0	26	0	78	23	34	17	396

a. Rehabilitation program

b. Preconditioning program

c. Inflight program

Since none of the crew members were found to require rehabilitation due to past injury or general weakness, there was no need for the rehabilitation program and it will not be discussed in this report. The preconditioning program was an attempt to train the crew so that they were in excellent physical condition prior to the flight.

This conditioning program was undertaken approximately 6 weeks prior to Flight I. The exercises utilized were designed to combat the following effects:

a. Loss of leg strength

b. Failure or impairment of bowel action

c. Loss of appetite

d. Increase in tension

e. Low back pain

f. Upper back pain from positional fatigue

g. Cervical pain.

The exercises were performed prior to the crew being resident at Martin and at the crew's discretion. While the crew was resident at Martin, the facilities of a local gym and of Martin were utilized. The first 6 weeks of the program the crew kept their own records as to time of exercise, weight, and number of repetitions of each exercise. During the pre- and post-flight evaluation period, records were kept by the physical therapist. The exercises performed by the crew during the preconditioning period are given in Appendix C.

Table 8 presents the approximate number of exercise sessions each crew member had prior to Flight I. Between Flights I and II and between Flights II and III, additional exercise periods were held but are not presented here. The crew also played handball and swam as part of their general conditioning program.

Table 8

Number of Exercise Periods

Crew Member	No. of Periods
Pilot A	25
Pilot B	30
Pilot C	20

The inflight exercise program was presented to the crew prior to Flight I by demonstration, and the crew held two practice sessions to familiarize themselves with the procedures. All exercises with the exception of two were performed by a stretch-type exerciser shown in Fig. 11. At maximum extension of this exerciser, approximately 600 inch pounds of work were exerted. These exercises are also presented in Appendix C.

Approximately 7 days prior to Flight I a physical conditioning evaluation was conducted. This included the following exercises:

a. Jumping jacks
b. Jump rope - both feet
c. Jump rope - one foot
d. Jump rope - stepping
e. Push-up
f. Sit-up
g. Chin
h. 50 lb. press.
i. 50 lb. back curl
j. 15 lb. swing bell

The number of repetitions and the total time required for each exercise were recorded. The crew was informed to do as well as they could on each exercise in consideration of completing all the above exercises.

One day before Flight II, another physical conditioning evaluation was conducted. This included the following exercises:

a. Jumping jacks
b. Jump rope - both feet
c. Jump rope - one foot

d. Push-up
e. Sit-up
f. 50 lb. press.
g. 50 lb. curl

The same data were collected as in Flight I. One day prior to Flight III, instead of an exercise evaluation procedure, a physical endurance procedure was conducted. This consisted of the Harvard Step Test for a 5 minute period. The procedure for this test are also presented in Appendix C. Blood pressures and blood samples were also collected with the step test.

5. Medical & Psychological Evaluation - Prior to Flight I (1-1/2 months) each crew member was given a thorough medical examination to ascertain the proper functioning of all body systems. The examination included the following areas:

a. Past history and review of systems.

b. General physical examination.

c. Laboratory studies

(1) Serology

(2) Urinalysis

(3) Blood count - white blood cells, sedimentation rate, hematocrit, and differential.

(4) Stool analysis

(5) Blood chemistry - urea, FBS, and cholesterol.

(6) Chest X-ray.

(7) Electrocardiogram and Double Master's Test.

(8) Pulmonary function test.

(9) Harvard Step Test

(10) Electroencephalogram

This evaluation indicated that all crew members were healthy individuals and could participate in the program.

Prior to and after each flight a brief 15 minute physical examination was conducted on each crew member. This was primarily to indicate any noticeable changes which might have occurred prior to the last examination. If any evidence existed to substantiate a more extensive examination, this would have been conducted. No evidence of this type occurred in any of the examinations.

A psychological and psychiatric examination was conducted on each crew member prior to Flight I (1-1/2 months). The psychological examination consisted of The Wechsler Adult Intelligence Scale and the Rorschach Projective Test. The Wechsler was given to ascertain basic capability of the individual while the Rorschach was given to determine personality characteristics and to obtain baselines for possible post-flight changes. All crew members were tested at the end of Flights I and III. However, the Rorschach was the only test administered at the end of each of these flights.

A psychiatric interview of each crew member was conducted prior to Flight I (about 1-1/2 months) and immediately after Flight I and Flight III. The interview consisted of 1-1-1/2 hour session to determine general personality traits by the interview techniques.

6. Behavior Response Tests & Troubleshooting Performance - Training and some baseline data were collected on each of these tasks prior to Flight I. Three tests were originally programmed for the behavioral response evaluation on Flight I. These were reaction time, time estimation, and immediate memory. The immediate memory tasks was discarded because of its time consuming nature and only time estimation and reaction time data will be discussed. Table 9 presents the number of trials each crew member received for training and baseline purposes. Inspection of this table indicates that no practice trials were given to Pilot C prior to Flight II since he did not participate as a pilot. Further, Pilot A and B received no practice prior to Flight III. The baseline data utilized on these two crew members for Flight III were their past performance on all trials prior to Flight III.

Crew training on the troubleshooting maintenance panel consisted of performing at least 10 trial troubleshooting tasks prior to Flight I plus discussing in some detail the strategies necessary for the various failures which could occur.

Table 9

Number of Practice Trials on Behavioral Response Tests

	Reaction Time										Time Estimation									
	Preflight I			Preflight II			Preflight III				Preflight I			Preflight II				Preflight III			
	1 sec	5 sec	15 sec	1 sec	5 sec	15 sec	1 sec	5 sec	15 sec	1 sec	5 sec	30 sec	60 sec	1 sec	5 sec	30 sec	60 sec	1 sec	5 sec	30 sec	60 sec
Pilot A	40	40	40	10	10	10	-	-	-	20	20	20	20	10	10	10	10	-	-	-	-
Pilot B	40	40	40	10	10	10	-	-	-	25	25	25	25	10	10	10	10	-	-	-	-
Pilot C	40	40	40	-	-	-	10	10	10	20	20	20	20	-	-	-	-	10	10	10	10

V. Results

This chapter will present the results of the three flights conducted during the study. The reported results are divided into the following areas: flight control task performance, navigational task performance, systems management task performance, duty cycle utilization, psychophysiological inflight measures, medical and psychological evaluation, and simulator displays, controls, and arrangement.

It should be noted again that performance of the crew will be compared primarily to pre-flight baseline data or data obtained from any of the other flights during the study.

A. Flight Control Task Performance

The results of this section are presented in terms of a description of each flight phase and the mode of simulation. In addition, the pilot's flight task is detailed, and information concerning performance parameters measured during baseline practice and during each of the flights are discussed. The displays utilized by the pilot in performing the flight control task are also presented. Further, the lunar mission simulation equations and analog schematics are presented in Appendices D and E respectively.

1. Flight Phase Performance

a. Earth Ascent:

The simulated launch date for each of the simulated flights was on March 25, 1968. Launch was from Cape Canaveral on an azimuth of 111°. The lunar spacecraft was boosted into a 100 n.m. parking orbit by a representative three stage Nova launch vehicle. Staging occurred at 152 sec. and 504 sec., and the third stage was shutdown at 694 sec. as the 100 n.m. circular orbit was achieved. This trajectory was calculated on a digital computer prior to the simulation and is shown in Fig. 15.

The velocity and altitude during the simulation were function generated and presented to the crew on appropriate control panel meters. Equations describing the vehicle angular motion were, however, computed and vehicle attitude was controlled by the Commander. The dynamic pressure during launch was also function generated so that a realistic simulation of aerodynamic damping was obtained. Further information concerning the simulated ascent aerodynamics can be found in Figs. 16 and 17.

The representative Nova launch vehicle consisted of three stages with thrust levels of 12×10^6 lbs., 1.6×10^6, and $.4 \times 10^6$ lbs. in the first, second and third stages respectively. The third stage had a restart capability but none of the stages were throttleable. The total weight at liftoff was 9.6×10^6 lbs. and the lunar spacecraft weight was $.161 \times 10^6$ lbs. The changes in vehicle mass and moments of inertia due to fuel consumption and staging were programmed into the angular equations of motion as detailed in Figs. 18 and 19.

Pitch and yaw attitude control was obtained by gimbaling the main engines and roll control was provided by separate reaction jets. Stability augmentation was provided in the form of artificial damping about the roll axis.

The control task during ascent required the Commander to follow a pitch program (Fig. 20) while holding a zero roll and yaw attitude, and to ignite, shutdown, and separate the three booster stages. Vehicle attitude information was presented on a three-axis ball. In addition, pitch and yaw error signals were presented on horizontal and vertical cross bars in front of the ball. Displacement of these bars from the center indicated the direction in which the pilot had to change the pitch and yaw angles in order to correct back to the proper attitude. Rotation rates about each axes were presented on separate meters.

The staging tasks were performed at specific times with reference to an elapsed time digital clock. Errors in staging time, however, did not effect the function generated trajectory. These tasks were included to provide other realistic tasks aside from the attitude control task. The primary measure of crew performance during the launch phase gave an indication of how well the vehicle attitude was maintained. The root sum square of the attitude errors (error integral) in pitch, yaw and roll was integrated from the time of lift-off to the time of achieving circular orbit. This parameter, is a relative measure only, and no absolute information such as orbital injection errors can be obtained from it.

b. Translunar insertion:

The Nova third stage spacecraft combination remained in the earth parking orbit for approximately 1 hour until the vehicle was in position for the translunar injection. The time spent in the parking orbit was used for systems checkout. The translunar injection was initiated at 1.092 hours after liftoff when the vehicle was in a position just north of New Guinea. Injection was achieved by increasing the inertial velocity by approximately 10,000 fps. The flight path angle at injection was 3°, relative to the local horizontal and the altitude was 760,000 feet. See Fig. 21 for the model trajectory.

Translunar injection was accomplished by reigniting the Nova third stage and attaining a velocity increase of about 9500 fps. At this point the Nova third stage was shut down and separated from the spacecraft. The vernier engines of the lunar landing module were then ignited, and the final 500 fps velocity increment was added.

The simulation of this phase consisted of mechanizing the equations of vehicle angular motion as in the launch phase plus the mechanization of a linear acceleration equation. The linear acceleration was integrated to provide the velocity increment.

The configuration at the beginning of the phase was the same as that at the end of the parking orbit insertion. The total mass was about 15,000 slugs and the main engine thrust was 400 K lbs. After separation from the third stage the mass was 4990 slugs, and the maximum thrust of the throttleable vernier engines was 12,000 lbs. total. The attitude control system of the spacecraft employed reaction jets; the signals to these jets came from the two axis sticks and the foot pedals in the command module.

The piloting task in the translunar injection phase was to follow a pitch program (Fig. 20) while holding the yaw and roll angles at zero. The staging tasks were the same as in the launch phase: switches were thrown at the specified times to ignite, shutdown and separate the third stage. The lunar landing module verniers were armed and then activated with a throttle, and the thrust level was controlled by the Commander as the final 500 fps velocity increment was added.

The vehicle attitude was presented on the 3-axis ball, however, the primary attitude control instrument was the CRT. Pitch and yaw angle errors were presented on this scope, and the pilot attempted to null these errors. On the first two flights the ΔV indication was also shown on the CRT, but for the last flight a digital readout of ΔV was added to the Commander's instrument panel.

Two parameters were recorded in this phase to give a measure of pilot performance. These were the "Error Integral" as described in the launch phase and the ΔV error at shutdown of the lunar landing module vernier engines.

No attempt was made to determine the trajectory variations that would result from these error parameters.

c. Midcourse corrections:

Three corrections were made in each of the translunar and transearth coasting periods. These corrections would be determined in terms of a velocity increment and direction from navigation fixes obtained by the crew. The velocity correction would be computed so that it would be applied at a specified time in the future. Just prior to this time the vehicle would be oriented to the correct position, and as the correction time was reached the lunar landing module verniers would be ignited. The thrust level used would depend on the magnitude of the ΔV required.

The simulation for the midcourse corrections was similar to that for the translunar insertion. Equations describing vehicle angular motion about each of the three body axes and acceleration along the vehicle longitudinal axis were mechanized. The decrease in vehicle mass and moments of inertia were not simulated however, because these changes were small. The velocity increments were also less than 50 fps, and approximately 30% of maximum thrust was used.

The corrections to be applied were presented to the crew via the closed-loop television system in the control room in terms of yaw and pitch attitude, ΔV required, and time to initiate as can be seen in Table 10.

The crew member on duty aligned the vehicle, and

Table 10

MIDCOURSE CORRECTIONS	
TRANSLUNAR:	**TRANSEARTH:**
Time - 4.125 hrs. ΔV - 23.75 Ft/Sec Yaw - ±38.26° Pitch - - 25.58°	Time - 13.01 hrs. ΔV - 36.0 Ft/Sec Yaw - - 32.6° Pitch - ± 5.3°
Time - 16.125 hrs. ΔV - 13.31 Ft/Sec Yaw - -167.80° Pitch - ± 16.70°	Time - 31.01 hrs. ΔV - 38.1 Ft/Sec Yaw - ±5.76° Pitch - -13.6°
Time - 61.125 hrs. ΔV - 32.522 Ft/Sec Yaw - -44.93° Pitch - -.303°	Time - 51.01 hrs. ΔV - 29.0 Ft/Sec Yaw - -13.42° Pitch - -5.0°

at the prescribed time ignited the LLM vernier engines. The control task of maintaining the vehicle attitude and monitoring the ΔV and the instrument panel displays were the same as during the injection phase.

The ΔV error was the primary parameter used to measure pilot performance during the midcourse corrections.

d. Lunar orbit insertion:

Insertion into lunar orbit occurred at pericynthion on the far side of the moon (see Figs. 22 and 23). A ΔV of -3070 fps was required to slow the spacecraft to circular orbit velocity at the pericynthion altitude of 100 n.m.

The simulation of this phase was similar to the translunar injection phase. The same equations of motion were mechanized, and the decrease in vehicle mass due to fuel consumption was included. The instrument displays utilized were the same as for the injection phase.

Attitude control was maintained with the reaction jet system and differential throttling of the verniers, and the lunar landing module main engine (J-2) and vernier engines (see Fig. 28) were used to provide the ΔV required. Figure 28 presents the engine arrangement for the main vehicle simulator. The main vehicle simulator had three main engines and four small vernier engines. The J-2 engine was mounted along a centerline of the vehicle with the verniers located around the periphery in the pitch and yaw axes. The LR-115 engines were located outboard of the J-2 engine in the plane containing the pitch and roll axes. Prior to reaching pericynthion, the Commander aligned the vehicle in the proper direction, and at the specified time the vernier engines were ignited at 1/6 of full thrust. Then the main engine, which was not throttleable, was ignited. The pilot task then, was to hold the correct vehicle attitude and monitor the ΔV indication. As the ΔV approached 3000 fps, the Commander shut down the J-2 engine, and the final 70 fps was removed with the vernier engines. The two primary measures of pilot performance during this phase were the ΔV error at shutdown of the vernier engines and the attitude error integral during thrusting.

e. Lunar deorbit:

The spacecraft remained in a lunar orbit at 100 n.m. altitude for about 32 minutes - or about one-fourth of one orbit. At the end of this time a deorbit maneuver was initiated by decreasing the velocity by 210 fps. This deorbit occurred at about the time the spacecraft reappeared from around the far side of the moon.

The simulation of this phase was similar to the midcourse correction phases. The equations of angular motion about the vehicle body axes and the equation of translational motion along the body longitudinal axis were programmed. The displays and attitude control tasks were the same as those phases also, however, the velocity control procedure was different.

The LR-115 engines on the lunar landing module were used to achieve the major part of the deorbiting ΔV, and the vernier engines were used for the final fps. (See Fig. 28).

The pilot tasks were to stabilize the vehicle at the correct attitude, and to ignite the LR-115's and the verniers at about 50% of full thrust. The pilot monitored the CRT to maintain the correct attitude as the ΔV increased. After about 160 fps of the required velocity increment had been achieved the LR-115's were secured, and at about 200 fps the verniers were throttled back and finally shut down at 210 fps.

The measures of pilot performance were the same as in the orbit insertion phase.

f. Lunar landing (Main vehicle):

A twenty-five minute coast period followed the deorbit maneuver. During this period, the spacecraft descended on an elliptic trajectory to an altitude of 43,000 feet. At this altitude the landing- or braking maneuver was initiated. The velocity and flight path angle at the start of this maneuver were 5535 fps and -4.55°. Retro-thrust was applied in conjunction with a pitch program to bring the vehicle from these initial conditions to a hovering condition at an altitude of 1500 feet. The J-2 engine and the vernier engines were used to provide the major portion of this deceleration. (See Fig. 28). A vertical descent to a landing was accomplished from the hovering state using the LR-115's and verniers for control of the rate of descent.

A three degree of freedom simulation of this phase was conducted. The equations of translational motion of the vehicle in the vertical plane and rotational motion about the pitch axis were programmed. Rotations about the roll and yaw axes were calculated, but they were uncoupled and did not affect the trajectory. The reduction of vehicle mass and moments of inertia due to fuel consumption were also simulated. See Figs. 24 through 27 for the simulated trajectory dynamics.

The configuration used for the main landing was the complete lunar spacecraft consisting of the lunar landing module, the command module and the service module as presented in Fig. 28.

The vehicle mass at the start of the braking maneuver was about 3230 slugs, and the thrust during this period was about 70,000 lbs. (J-2 plus verniers). The thrust level during the vertical descent, using the throttleable LR-115's and verniers, varied from 12,000 lbs. to 20,400 lbs. Attitude control was maintained by differential thrusting of the vernier engines. (See Fig. 26).

The pilot endeavored to stay on a nominal path during the braking phase by following a pitch program. In addition to vehicle attitude, velocity and altitude information on the instrument panel, the pilot was given a special display on the CRT. A static curve of velocity versus altitude (Fig. 24) for the nominal braking trajectory was presented on the CRT, along with a dynamic dot that showed the vehicle's actual velocity and altitude. The task was to keep the dot moving along the curve as the vehicle decelerated. To aid in following the nominal pitch, a pitch angle error was presented on the CRT. The technique was to position the vernier throttle at the nominal setting (J-2 was on but not throttleable) and to hold the pitch error at zero. If the dot strayed off the nominal curve, a pitch angle error was deliberately held in the direction necessary to bring it back. While keeping the vehicle on the nominal path the pilot also had to monitor the 3-axis ball and the rate meters to maintain zero roll and yaw attitude.

The commanded pitch rate was very slow during this maneuver until the velocity was reduced to about 160 fps

At this time the LR-115's were ignited, the J-2 was cut, and the vehicle was pitched up rapidly to a vertical attitude. The final pitch-up, if done perfectly, eliminated the horizontal velocity, and all that remained was to maintain the proper attitude and control the rate of descent with the throttle. The final 1000 ft. of altitude was presented on the CRT (See Fig. 29C).

It is significant that although the pilot was trying to fly a nominal trajectory, the simulation was not restricted to perturbations about this nominal. And a successful - or safe - landing could be accomplished by the pilot without following the programmed trajectory. Note also that there was no program for the vertical descent.

The primary measures of pilot performance during this phase were the touchdown conditions; $\dot{h}$, $\dot{x}$, θ , ψ , ϕ , $\dot{\theta}$, $\dot{\psi}$, $\dot{\phi}$, and the total amount of fuel used.

g. Lunar landing (Excursion vehicle):

The simulated excursion vehicle was considerably smaller than the main vehicle, having a mass of about 435 slugs while in lunar orbit prior to descending. The maximum thrust of the throttleable main engine of 9160 lbs. was sized so as to give the same deceleration as the main landing vehicle. Because the deceleration characteristics were the same, the trajectories flown by the excursion vehicle and the main vehicle during de-orbit, coasting and braking to landing were the same.

The flight attitude controls of the two vehicles were similar. The excursion vehicle had a two-axis stick plus foot pedals with which to provide inputs to the reaction jet controls. However, the response was more rapid with the excursion vehicle due to higher torque to inertia ratios.

Although the CRT displays were identical for the two vehicles, the attitude indicators were different. The excursion vehicle had a two-axis ball which showed pitch and roll angles. The yaw angle was shown on a separate meter below the ball. Pitch and roll rates were indicated by a LABS instrument and yaw rate was displayed on a separate meter. In general, the display panel in the excursion vehicle was considered to have

a much poorer layout and scan pattern than the main vehicle.

The pilot tasks were the same for the excursion simulator as in the main simulator lunar landing with the exception of the engine management functions. Once the braking maneuver was begun, there were no engines to shut down or ignite. The same parameters were recorded to indicate pilot performance as in the main vehicle landing.

h. Lunar ascent:

The lunar ascent model trajectory was a two-dimensional, three degree of freedom phase. During the powered phase, the thrust was a constant ($T/W_{initial}$ = .4). The nominal burning time was 348.5 seconds, and the spacecraft coasted to a 100 n.m. apocytheon (See Figs. 30 and 31). The spacecraft was then pitched over, and the necessary ΔV imparted to achieve a 100 n.m. circular orbit. A pitch program of 2°/sec. was required for the first 5 seconds of ascent.

The same ascent trajectory was used for both the main vehicle and the excursion vehicle. The simulated trajectory gave the pilot control over vehicle attitude and engine thrust. Altitude was functioned generated. The last 200 ft/sec. of velocity was generally imparted with the service module verniers.

The pitch-over maneuver and subsequent insertion into lunar orbit was not simulated. Instead, at the end of the powered phase, the main ship was pitched over 80° via a 2°/sec. pitch program. This maneuver was not performed with the excursion vehicle. The vehicle characteristics for the main and excursion vehicles are shown in Table II.

Further, a 2 deg. peak to peak noise signal was impressed on the pitch channel to provide a more realistic tracking task. The white noise input was channeled through a 1 radian filter to simulate the low frequency inputs likely to result from erratic engine burning, for example, and general system functioning.

Table II

Characteristics of the Main & Excursion Vehicles

EVENT	TIME	NOMINAL THRUST (Lbs.)	I_{sp} (Sec^{-1})	WEIGHT (Lbs.)	I_{Roll} ($Slug-Ft^2$)	I_{Pitch} ($Slug-Ft^2$)	I_{Yaw} ($Slug-Ft^2$)	Pitch-Yaw Moment Arm (Ft.)	DURATION (Sec.)
1. Earth Ascent	0	See Figure 1							694
2. Parking Orbit & Translunar Insertion	52 Min	See Figure 1							271
3. First Mid-course Correction	4.125 hr	4000.	306.	137,000	48,900	877,470	877,700	14.71	25.2
4. Second Mid-course Correction	16.125 hr	4000.	306.	136,633	48.900	877,470	877,700	14.71	14.08
5. Third Mid-course Correction	61.125 hr	4000.	306	136,449	48,900	877,470	877,700	14.71	34.35
6. Lunar Orbit Insertion	71.88 hr	54,188	425	136,000	48,900	877,470	877,700	15.50	216.2
7. J-2 Shutdown into Lunar Orbit	71.94 hr	--	---	107,000	47,594	671,360	670,292	15.90	---
8. Initiate Deorbit									
A. Main	72.466	22,000	410	107,000	47,594	671,360	670,292	16.31	34.6
B. Excursi n	72.466	2879.	410	14,000	337	3369	3369		34.6

Table II (Cont'd.)

Characteristics of the Main & Excursion Vehicles

EVENT	TIME	NOMINAL THRUST (Lbs.)	I_{sp} (Sec^{-1})	WEIGHT (Lbs.)	I_{Roll} ($Slug-Ft^2$)	I_{Pitch} ($Slug-Ft^2$)	I_{Yaw} ($Slug-Ft^2$)	Pitch-Yaw Moment Arm (Ft.)	DURATION (Sec)
9. Lunar Coast									
A. Main	72.476 hr	---	---	104,000	47,495	655,720	654,480	16.35	1715.5
B. Excursion	72.476	---	---	13.621	329.	3290.	3290.		1715.5
10. Initiate Braking Maneuver									
A. Main	72.953 hr	70,000	425	104,100	47,495	655,720	654,480	17.27	212.
B. Excursion	72.953 hr	9160.	425	13,621	329.	3290.	3290.	17.0	212.
11. J-2 Shut-down (Begin Terminal Maneuver									
A. Main	73.012 hr	20,400 to 12,000	425	69,391	45,600	345,000	345,000	18.19	38.5
B. Excursion	73.012	2,670	425	9080.		173.	1733.		38.5
12. On the Moon									
A. Main	73.023 hr	---	---	68,071	45,520	343,990	340,680	18.19	---
B. Excursion	73,023 hr	---	---	8907.	172.	1717.	1717.		
13. Lunar Takeoff									
A. Main	0	[illegible],435	306	46,063	21,280	39,657	37,293	7.23	348.5
B. Excursion	0	3563.	306	8907	172.	1717.	1717.		348.5

Table II (Cont'd.)

Characteristics of the Main & Excursion Vehicles

EVENT	TIME	NOMINAL THRUST (Lbs.)	I_{sp} (Sec^{-1})	WT (lbs)	I_{Roll} (slug-Ft^2)	I_{Pitch} (slug-Ft^2)	I_{Yaw} (slug-Ft^2)	Pitch-Yaw Moment Arm (Ft)	DURATION (Sec)
14. Lunar Orbit Insertion									
A. Main	28.5 min	5140	306	25,000	13,773	24,894	22,618	7.50	46.
B. Excursion (Rendezvous)		.1 to .01 g	306	4834.	108.	1078.	1078.		
15. Transearth Insertion	1.00 hr	48,000	306	24,230	13,500	24,300	22,100	7.58	45.
16. First Midcourse Correction	13.01 hr	2000	306	17,500	11214.	19863.	17617.	7.60	14.1
17. Second Midcourse correction	31.01 hr	2000	306	17,408	11214.	19863.	17617.	7.60	10.2
18. Third Midcourse correction	51.01 hr	2000	306	17,341 W_P = 17,290.	11214.	19863.	17617.	7.60	8.0
19. Begin Reentry	70.21 hr	0-280	288	9291	4766	4387	3787	--	1680.
20. End Reentry	70.67 hr	0-280	288	8211	4047.	3515.	3469		

54.

NR-12693

1. Rendezvous:

The rendezvous system used in the simulation was similar, in part, to that employed in an earlier Apollo orbital rendezvous study. The excursion vehicle was given a set of initial conditions with respect to the main vehicle and the subsequent trajectory remained strictly up to the individual pilot with the primary task being to simultaneously null both the distance and velocity of the excursion vehicle with respect to the main vehicle.

The initial acquisition of the main ship by the excursion vehicle was performed by means of visual tracking. A flashing main vehicle image was projected on a starfield located on the simulator enclosure wall. The pilot aligned the excursion vehicle with the main vehicle by means of the position of the flashing light on the star background. This mode of rendezvous was maintained until the x and y rates were nulled at which time a CRT display was activated.

A Lissajous pattern on the CRT (see Fig. 32) presented the relative position and distance of the main ship. There were two lens settings on the CRT: one corresponding to a 45° field of view, and the other to a 2° field of view. The change in lens setting was usually made when the main ship image was exactly centered in the CRT crosshairs inasmuch as a significant increase in sensitivity was realized.

Two throttle settings were available to the pilot and capable of providing .1g and .01g accelerations. In general, the rendezvous maneuver was accomplished by driving the initial x and y displacements to zero, and then slowly reducing z to zero. This action corresponds to nulling the lateral and longitudinal displacements and then nulling the altitude difference.

Vehicle characteristics are shown in Table II. The vehicle was assumed to have six engines: two for translation in each direction. Automatic attitude stabilization was continuously provided throughout the rendezvous. In order to provide the accuracy required for the docking phase, the terminal readings on ρ (< 150 ft.) were confirmed by the ground monitor because of display limitations.

j. Transearth insertion:

Transearth insertion refers to that phase of flight where the spacecraft leaves lunar orbit and begins the return to earth. The service module provides the necessary propulsion for this phase.

The particular transearth trajectory simulated was in the Moon's orbital plane (inclined 28.5 degrees to the Earth's equator - (see Fig. 33). Transearth insertion took place directly behind the Moon, on the Earth-Moon line. The velocity increment necessary for this phase was 2989 ft/sec. There was no pitch program.

The vehicle characteristics for this phase are shown in Table II. The pilot's task was to control the vehicle's attitude (pitch, yaw and roll), and to accelerate the spacecraft to the proper velocity. The last 100 ft/sec. of velocity was imparted with the Service Module vernier engines. The same measures as in lunar orbit insertion were taken.

k. Re-entry and earth landing:

The trajectory employed in the re-entry phase of flight was generated by means of a digital simulation program using a predictive guidance scheme (Ref. 47) which provided a lift time history for the 0.5 L/D command module. The commanded roll angle (corresponding to the required L/D ratio) was generated as a function of time and presented on the periphery of the CRT in the form of a command signal (see Fig. 29D). The vehicle's immediate roll attitude was also displayed so that a direct indication of roll error was available to the pilot. By displaying altitude error and altitude rate error the immediate effect of an accidental or deliberately held roll error was also available.

The longitudinal range of the assumed recovery site (Southwestern U.S.) was 5900 n.m. with no lateral target offset. (See Fig. 34). The command module entered at a -7° flight path angle (measured at 400,000 ft.). Because of the limited lift available with the 0.5 L/D vehicle an atmospheric skip maneuver was required. An altitude-time history of the flight trajectory is shown in Fig. 35 demonstrating the shape of the skip trajectory.

Because lateral range must be controlled with the re-entry configuration employed by managing the direction of the lift vector, a number of roll-reversal commands (4) are located throughout the trajectory (Fig. 36). These reversals were anticipated for the Commander by the small cursor moving horizontally across the bottom of the CRT. As the cursor crossed the vertical bar dividing the scope, the roll-over command was executed. The ability of the pilot to follow this command is reflected in the magnitude of the error integral contribution for each roll-over maneuver. It should be noted that the pilots were instructed to roll past the commanded bank angle to eliminate the $\dot{h}_E$ obtained in each roll. Though, this added to the error integral, it was a required technique because of the display and system simulated.

In general, then, the pilot's procedure during re-entry consisted of the following tasks:

(1) Release of Service Module.

(2) Assume entry attitude.

(3) Control altitude and altitude rate errors by rolling the vehicle.

(4) Control pitch and yaw attitude.

(5) Perform roll -over maneuver.

(6) Initiate drogue chute and main chute deployment.

The control of altitude and altitude rate errors was accomplished by increasing or decreasing the vehicle's roll angle beyond the commanded attitude. The effectiveness of this action was, of course, a function of dynamic pressure and required a strict monitoring of the error-altitude relationship in order to assure correct exit conditions for the free-flight phase of the trajectory. Fig. 37 presents the nominal altitude rate-dynamic pressure relationship.

Auxiliary damping in the pitch and yaw axes was maintained throughout the flight (damping ratio of 0.5), while no damping beyond that normally supplied by the aerodynamics was included for the roll axis. Insofar as this simulation was concerned, no coupling between axes took place.

The re-entry vehicle was generally returned to the automatic control mode by the Commander whenever it operated above 400,000 ft., such as during the skip-out.

2. Simulation Performance Results

The following section contains a brief description of the results for the dynamic control aspects of Flights I, II and III. The discussion is divided into the various dynamic phases of flight with particular emphasis being devoted to the lunar landing phase.

Because of the constant improvements and changes introduced throughout the study, the task of directly contrasting trials made at different times within any particular phase of flight was somewhat difficult. Therefore, in the process of evaluation of any questionable control areas, a concerted effort has been made to give the crew the benefit of any doubt.

A complete tabular collection of all data obtained during the practice, the baseline and the flight trials, can be found in Tables 12 through 21.

a. Earth ascent:

Since only the Commander performed this task during each flight and this position billet was rotated among the three crew members for the different flights, baseline data was taken only for the appropriate crew member prior to each flight.

The integrated root sum square of the attitude errors, denoted by $\int e$, was integrated from lift-off to parking orbit insertion to provide a measure of pilot performance. The Commander's task was to follow a pitch program while maintaining a zero yaw and roll attitude. "White Noise" (2 deg. peak to peak with a 1 radian filter) was added to the pitch attitude display to complicate the task.

The results of the practice, baseline, and flight trials are presented in Table 12. A typical analog recorder trace showing some of the more interesting parameters is presented in Fig. 38. These data can only be used to show relative performance since the absolute magnitude as presented cannot be interpreted in terms

Table 12 - Earth Ascent Performance Results

Trial No.	Pilot	Remarks
51	A	1064
52	A	944
53	A	994
54	C	4220
55	C	1427
56	C	1104
57	C	926
58	C	1122
59	B	691
60	B	860
61	B	846
62	B	800
Flt. I	C	892
230	A	1114
231	A	1155
232	A	1015
233	A	1320
Flt. II	A	1177
404	B	1392 (Yaw Drift in Computer)
405	B	842
Flt. III	B	646

of trajectory variations. A definite decrease in the integrated error was noted as more experience was gained. This "learning curve" trend appeared to approach a minimum during the first flight with Pilot C. The data for Pilots A and B, who commanded the second and third flights respectively, show very little scatter. The flight results for "A" were slightly higher than the baseline average, while the results for "B" were lower than any of the baseline data.

It is concluded that there was no significant difference in performance level between baseline and flight data for the Earth Ascent phase. Furthermore, it was found that there was no significant decrease in performance after a two or three week "lay off" period on this phase.

b. Translunar insertion.

Piloting tasks during the translunar insertion were also performed by the Commander. Therefore, the method of obtaining baseline data was similar to that used for the ascent phase. Although the attitude control tasks for these two phases were similar, (principally to follow a pitch program), a different instrument was used as the primary source for attitude reference. The pitch and yaw angle error was presented on a CRT display, and the pilot task was to keep a dot centered at the "zero-zero" position on this display. (Fig. 29A).

In addition to the attitude control task, the pilot was required to shut down the engines when the correct velocity increment was attained. This differed from the ascent phase where all staging operations were performed at specified times. The velocity error at shutdown provided a second measure of pilot performance. The velocity errors and integrated root sum square attitude errors gathered during the baseline runs and the flights are listed in Table 13.

The insertion data for Flight I with Pilot "C" in command was not recorded, however, the four recorded baseline runs indicate that the minimum point of the "learning curve" for this particular phase was attained just prior to the flight.

Table 13 - Translunar Insertion Performance Results

Trial No.	Pilot	ΔV Main Engine	ΔV Total	$\int e$ Main Engine	$\int e$ Total	Time Sec.	Remarks
209	C	9522	10006	1128	2690	-	
210	C	9545	10008	700	1809	554	
211	C	9681	10005	643	1373	468	
212	C	9715	10000	804	1530	436	Bench Mark Installed on CRT Display at 9500 fps.
236	A	-	10013	-	1314		Noise introduced on Θ_E
237	A	-	10006	-	607		
238	A	9745	10012		800		
Flt. 2	A	10000	10090	-	2822	-	Verbal instructions given by Control Room in error.
402	B	-	10010	-	1417		Digital readout installed.
403	B	-	9999	-	1575		
Flt. 3	B	-	10000	-	2140		$\int e$ = 1600 during thrusting.

It can be seen from Table 13 that the flight performance for Pilot "A" was much worse than the baseline data. However, this large increase in the error parameters was not attributed to a decrease in pilot performance. In Flight II erroneous instructions were given to the Commander by the control room.

A change was made in the display prior to Flight III. During the first two flights the velocity increment was determined by the position of a cursor on a scale of the CRT (see Fig. 29A). For the third flight, a digital readout of velocity increment was also available to the pilot.

The data for Pilot "B" was obtained with the pilot using the digital display. The results indicate that the velocity could be more accurately controlled when using the digital readout, as would be expected. The attitude errors for Flight III were slightly higher than the baseline, however, the maximum variation was only about 10% and was not considered significant.

During Flight II, Pilot "A" erroneously ignited the lunar landing module verniers 4 sec. prior to a late separation of the booster's third stage. This mistake could have resulted in serious damage to the landing module, but would most likely be impossible in flight hardware due to safety interlocks. It should be noted that only the ΔV scores obtained in Flight III are representative of performance since the lack of a digital display in Flights I and II made adequate pilot performance difficult.

c. Midcourse corrections:

The midcourse corrections required the pilot to orient the vehicle in a certain direction and attain a specified velocity increment. The velocity error at cutoff was the primary measure used to determine crew performance.

Changes made in the crew duty cycle between Flight I, Flight II, and Flight III resulted in a different distribution among the pilots of the number of midcourse corrections. The CRT display was the same as the preceding phase with the exception of the magnitude of the velocity increment scale. The velocity indicator was changed between each flight to improve the display, so

that direct comparison between the flights is not entirely valid.

The average velocity errors for the three corrections for Flight I (see Table 14) were not considered significant. This was not attributed to a decrease in the pilot's performance level, since the largest error occurred on the first correction which was only four hours after lift-off. It was believed that the relatively poor control of cutoff velocity was due to the poor velocity presentation. For the first flight, full scale of the velocity indication on the CRT was 100 fps with marks at every 12.5 fps increment (Fig. 29A). The baseline trials prior to this flight were made for a correction of 50 fps. This point was well indexed and there was no difficulty in cutting off at the correct value. During the flight, however, all of the required corrections were such that the pilots had to visually interpolate on a very poor scale.

A procedural error was made on one of the corrections during this flight. During the second correction the vehicle was not oriented in the correct yaw attitude. This error is attributed to insufficient training of the pilot in order to combat any forgetting which occurred.

Prior to Flight II, the scale on the velocity presentation was changed (see Fig. 29B). The full scale on the CRT for this flight represented 40 fps with graduations every 1, 5 and 10 fps. The results for this flight indicate the advantages of the smaller scale. Pilot "A" (Commander during Flight II), without any practice between flights, was able to keep the velocity errors to less than 0.5 fps. Note that interpolation was still required with this display but was between smaller increments.

After Flight II a digital readout of velocity increment was installed. The scale was such that .01 fps was easily readable. The results obtained with this presentation did not show any marked decrease in the velocity error below those obtained in Flight II. There is a sufficient amount of data with the digital readout, however, to indicate the velocity error can be held to about 0.2 fps. It should, however, be noted that the digital readout that was used in the simulation

Table 14 - Midcourse Corrections Performance Results

Trial No.	Pilot	ΔV - Ft/Sec. Req.	Act.	Δ_V	Remarks
213	B	50	51.7	1.7	0-100 ft/sec. scale
214	B	50	49.9	-0.1	
215	C	50	49.8	-0.2	
216	A	50	49.2	-0.8	
217	A	50	49.9	-0.1	
Flt. 1-1	C	23.75	30	6.25	
Flt. 1-2	A	13.31	16.5	3.19	
Flt. 1-3	B	32.52	36.06	3.54	
Flt. 2-1	A	23.75	23.83	.08	0-40 ft/sec scale substituted.
Flt. 2-2	A	13.31	12.72	.38	Display read 13.3 ft/sec.
339	B	32.52	32.63	.11	Digital readout of Δ V added to display panel.
340	B	32.52	32.90	.38	
341	B	32.52	32.74	.22	
342	C	32.52	32.73	.21	
343	C	32.52	-		
344	C	32.52	-		
345	C	32.52	32.72	.20	
346	C	32.52	32.74	.22	
Flt. 3-1	A	23.75	24.00	.25	
Flt. 3-2	C	13.31	13.5	.19	
Flt. 3-3	B	32.52	33.55	1.03	
Flt. 3-4	C	36.00	54.30	18.30	
Flt. 3-5	B	38.10	42.40	4.30	
Flt. 3-6	A	29.00	29.75	.75	

also had its limiations. When the rate of change was extremely rapid, accurate and exact interpretation was also difficult.

The third midcourse correction during Flight III provided an interesting result. The correction by Pilot "B" was in error by 1.03 fps. This was four times greater than the baseline average for this pilot. This correction was applied 61 hours after lift-off and the possibility of a decrease in pilot performance should be considered. The post-flight remark by Pilot "B" to the effect that this translunar coast period was the most tedious period of the entire flight lends some weight to the conclusion that pilot performance might be adversely affected during this period. However, Pilot "A's" performance on the last transearth midcourse correction, made many hours after Pilot "B's", indicated good performance with an error of only .75 fps.

Midcourse corrections during the transearth phase were generally not considered representative of pilot performance. The vehicle acceleration for these corrections was about 6 times as great as that during the translunar phase. The crew had not practiced corrections at this higher acceleration level, and it was felt that data recorded during the flight would not be meaningful. Therefore, Pilot "A's" performance on the transearth midcourse correction is indeed an indication of high performance after more than 100 hours of flight.

d. Lunar orbit insertion:

The performance parameters recorded for lunar orbit insertion were the integral of the root sum square of the attitude errors ($\int e$) and the insertion velocity error. This phase was performed by the Commander during each flight.

The pitch and yaw attitude errors were displayed on the CRT, as during the preceding phase, along with a velocity increment scale. The full scale on the velocity indicator corresponded to 4000 fps (a ΔV of 3070 fps was required) with graduations of 100, 500 and 1000 fps. (Fig. 29E). This display remained unchanged between Flights I and II. However, noise was added to the pitch error signal subsequent to the first flight, and a digital readout of velocity increment was added after the second flight.

Table 15 - Lunar Orbit Insertion Performance Results

TRIAL NO.	PILOT	$\int e$	ΔV_e	REMARKS
218	A	69	-158	ΔV Always 3070 ft/sec. for all flights.
219	"	42	- 69	
220	C	166	- 62	
221	"	49	- 16	
Flt. I	C	184	-154	
247	A	148	+ 25	Noise added to Θ_e Display
248	"	150	- 22	
249	"	117	- 11	
250	"	153	+ 3	
Flt. II	A	103	+ 7	
408	B	616	- 1	Digital read-out installed
409	"	622	- 5	
Flt. III	"	704	- 2	

The data (Table 15) indicates that Pilot "C" had a velocity error in Flight I that was four times as large as the average of the baseline data. The integrated attitude error was about 70% greater than the baseline average.

The results for Flight II show that Pilot "A" performed better during the flight than during the baseline trials for which there was "noise" in the pitch error signal. The effect of the "noise" can be seen by comparing the baseline data for "A" taken before and after Flight I. The average of the integrated attitude errors increased by a factor of about 2.5. It is interesting to note that it was only after five practice runs that Pilot "A" was able to bring the velocity error down to less than 10 fps.

The advantage of the digital velocity display is again apparent in the results for Pilot "B". Although only three insertions were made, including the flight phase for Flight III, the pilot was able to keep the velocity error to 5 fps or less in each case. The integrated attitude errors for Pilot "B" were a factor of four greater than those of the other pilots. It seemed possible that because the digital velocity readout was located separately from the CRT, the pilot was not able to devote as much attention to the attitude presentation. This would explain the greater attitude errors of Pilot "B". This conclusion was further substantiated by comparison of other phases where the displays for all three pilots were the same. In these cases Pilot "B's" performance was at a comparable level with the other pilots.

The possibility exists that Pilot "C" experienced some decrement in performance during the lunar orbit insertion in Flight I due to forgetting of the displayed parameters. The large errors during Flight I might then be considered a result of insufficient training and practice, rather than a loss of pilot efficiency.

e. Lunar deorbit:

The results for lunar deorbit are presented in Table 16. The commanded ΔV was 210 fps. Again it is apparent with the addition of a digital display of ΔV after Flight II, crew performance on obtained ΔV showed no decrement during Flight III when compared with

Table 16 - Lunar Deorbit Performance Result

TRIAL NO.	PILOT	ΔV_o	$\int e$	REMARKS
Flt. II	A	- 2.68	264	Main vehicle V_o always 210 fps for all alts.
"	B	8.16	141	Main vehicle
"	A	7.08	230	Excursion vehicle
"	B	- 0.60	*1276	Excursion vehicle
251	A	- 2.20	685	Main vehicle
252	"	0.30	528	Main vehicle
253	"	- 1.00	469	Excursion vehicle
254	"	0.20	573	Excursion vehicle
256	B	1.50	523	Excursion vehicle
256	"	- 0.90	484	Excursion vehicle
257	"	- 2.10	557	Main vehicle
258	"	1.60	549	Main vehicle
Flt. III-1	C	0.50	1887	Main vehicle
-2	B	0.70	495	Main vehicle
-3	A	- 0.80	627	Main vehicle
-4	C	0.00	327	Excursion vehicle
-5	B	0.30	951	Excursion vehicle
-6	A	1.60	194	Excursion vehicle

preflight III baseline. The integrated error scores generally showed no decrement in performance. The high error for Pilot "C" in Flight III is not considered a performance decrement due to any stress but rather a misinterpretation of instructions given to the pilot. All other scores for all pilots are highly comparable to baseline trials.

f. Lunar landing:

Consistent with other phases of flight, a typical landing trajectory was chosen from a six-degree of freedom simulation recently completed at the Martin Company (Ref. 48). This investigation involved a manual landing system based upon a predictive terminal condition approach. Inasmuch as numerous manual and automatic runs culminating in a soft touchdown on the lunar surface were demonstrated with this system, a representative trajectory taken from these results was believed to be in keeping with the manual emphasis of the present study.

The first simulation approach taken was a function generation of the landing trajectory and important flight parameters coupled with a set of perturbation equations to allow a realistic feedback of the piloting error. A CRT display of altitude error (h_e), altitude rate error ($\dot{h}_e$), range rate error ($\dot{x}_e$), and pitch program error (θ_e) was presented to the flight commander whose task it was to null all indicated errors. This was to be accomplished primarily by positioning of the vehicle thrust vector and by throttling of the landing engines.

Many attempts were made to fly the landing "wire" and although some successful runs were completed, the use of time as the independent variable in the function generation resulted in an intolerable situation whenever the flight trajectory deviated from the nominal by a comparatively small margin. Consequently, a second approach was undertaken which theoretically should have eliminated the troubles experienced with the first method.

The perturbation equations were discarded and a general set of three-degree-of-freedom motion equations substituted. This substitution provided a description of the vehicle motion in the vertical plane. The uncoupled roll and yaw moment equations were included to enhance the realism of the control task as well as to provide representative touchdown conditions in all vehicle axes.

The commander then had complete control over the flight trajectory - - he could either follow the display cues presented to him, or ignore these cues. In order that a measure of his progress could be made, an altitude-velocity profile representative of the nominal flight trajectory was presented on the face of the CRT (Fig. 29C) along with the spacecraft's immediate altitude-velocity relationship. Pitch program error was again presented to allow a comparison of immediate dynamic conditions to the nominal parameters generated as a function of time. To provide an integrated aspect to the terminal phase of flight, a moving index representing the vehicle's actual velocity and altitude appeared on the right hand side of the CRT display and indicated the last 1000 feet of altitude above the moon's surface. Further, velocity, altitude, and $\dot{h}$ were also presented on meters.

The task of landing either the main vehicle or the excursion vehicle with acceptable touchdown conditions, however, was not easy. A considerable amount of training and instruction was necessary before the crew became acclimated to the particular instrument layout and handling qualities associated with each configuration. A brief review of the vehicles, their individual propulsion compositions, and the manual procedure generally used in the landing maneuver is presented below.

(1). Main simulator

The main landing configuration is shown in Fig 28. This is the configuration studied in detail and presented in the Martin Company's Apollo proposal to the NASA. The main vehicle simulator was built and designed around this proposed command module configuration. The location of the engines has been discussed previously.

The large J-2 engine was used to perform the major portion of the braking maneuver with the 4 vernier engines (throttleable to 10%) being used for attitude control by means of differential thrusting. The two LR-115 engines were ignited when the vehicle began what was called the terminal phase of the braking trajectory (see Fig. 26). At this time, the J-2 engine was cutoff and the remainder of the landing completed with the LR-115 and vernier engines. Because precise trajectories employing the main vehicle dynamics and propulsion equipment were not available for a completely integrated trajectory, a certain amount of license was exercised in adjusting the thrust levels of the J-2 and LR-115 engines so as to be compatible with the thrust-to-weight ratio trajectories that were available for the simulation (see Table 17).

The method used by the crew in performing the landing maneuver is presented in detail below because of its importance. (The vehicle was assumed to be initially in a free fall condition in the coast phase of the landing trajectory).

(a). Vehicle control was switched to the manual mode.

(b). Pitch, yaw and roll errors were nulled (the initial pitch attitude required for the braking phase was - 10°).

(c). As the vehicle passed through 43,000 ft. altitude, the verniers and then the J-2 engines were ignited. (The nominal thrust level of the J-2 was fixed at approximately 68,000 lbs. The vernier engines were throttled back to approximately 2000 lbs. total, or 1/6 of full thrust).

Table 17

Lunar Landing Module Thrust Levels

EVENT	THRUST LEVEL (LBS)			
	VERNIER	LR-115	J-2	TOTAL
Maximum Thrust	12,000	30,000	200,000	
1. Ascent & Insertion	See Figure 1 for Launch Vehicle		---	---
2. Translunar Midcourse Correction	4,000 (1/3 Throttle)	Off	Off	
3. Lunar Orbit Insertion	2,188	Off	52,000	54,188
4. Lunar Orbit Maneuver	2,000	20,000	Off	22,000
5. Braking Maneuver	2,000	Off	68,000	70,000
6. Terminal Maneuver	2,000	18,400 to 10,000	Off	20,400 to 12,000

Service Module Thrust Levels

EVENT	THRUST LEVEL (LBS.)		
	SERVICE MODULE - MAIN	VERNIER	TOTAL
Maximum Thrust	41,000 Lbs/Eng - 3 Eng.	16,800	
1. Lunar Takeoff	14,000	4,425	18,425
2. Lunar Orbit Insertion	0	5140.	5140.
3. Transearth Insertion	41,000	7000.	48,000
4. Transearth Midcourse Corrections	0	2000.	2000.

(d). As the vehicle velocity dropped to approximately 160 ft sec., at a nominal altitude of 1500 feet, the terminal phase of flight was initiated. The J-2 engine was cut and the LR-115's immediately ignited. A comparatively fast pitch-over rate was then introduced theoretically nulling the range rate ($\dot{x}$) and leaving the vehicle falling vertically at something less than 100 ft/sec.

(e). By monitoring the $\dot{h}$ readout, in combination with the altimeter, the vehicle was lowered to the lunar surface by proper throttling of both the LR-115 and the vernier engines. Vehicle attitude was constantly controlled throughout the settling maneuver to assure a near vertical descent.

(2). Excursion simulator:

The excursion vehicle configuration had one gimballed engine which was used to provide propulsion from the time of deorbit until the initiation of rendezvous with the main vehicle. A completely throttleable capability was assumed and an auxilliary set of reaction jets were employed for roll control. A nominal maximum thrust level of 9160 lbs. was used for control of the braking and terminal phases. This thrust level, coupled with an initial vehicle weight of 9160 lbs., provided a thrust-to-weight ratio of 0.67. This value is identical to that of the main vehicle.

The procedure and information displays utilized in the excursion vehicle landing maneuver did not differ from that described for the main vehicle except for the lack of propulsion sequencing. However, because of a lack of room in the excursion vehicle, the resulting scan pattern was more awkward (see Fig. 8). The instrumentation, as described earlier in this report and contrasted with that provided in the main ship, provides some feeling for the extent of the differences between the two simulators.

(3). Landing procedure:

A number of operational procedures were required during the landing maneuver involving the lowering of the landing gear, sequencing of the engines, etc. While effort was expended during the collection of the baseline data to note procedural errors, no attempt at meticulous examination of the flight records were made. Therefore, the number of procedural errors and omissions reported in the following section may not be above the normal incidence for the particular task under discussion.

There is no question as to the importance of these errors inasmuch as perfect touchdown conditions with the landing gear not extended is still an unsuccessful landing. The point which should be emphasized, however, is that many of these errors would not be expected to be possible occurrences in flight hardware because of interlock circuits and audible warning devices which are an integral part of any automatic-manual control system.

(4). Landing abort procedures:

An abort capability was built-in to both the main and excursion landing maneuvers in order to assess the effect of an emergency situation upon the crew. The crew members were instructed to follow the procedures listed below:

(a). Cut the J-2 engine first and then the vernier engines.

(b). Ignite the service module vernier engines (this operation automatically detonates the explosive bolts connecting the landing and service modules thereby initiating separation).

(c). Ignite the service module main engines.

(d). Pitch the vehicle to the normal ascent attitude (pitched 100° from local horizontal) and roll through 160°. The roll-

over maneuver was designed to restore the normal control relationship which charged sign as the vehicle was pitched up and through 90°. The roll of 160° was dictated by computer limitations rather than trajectory requirements.

(e). Complete the remainder of the abort flight as though flying a normal ascent trajectory.

Excursion Vehicle -

(a). Advance the engine throttle to full thrust.

(b). Pitch the vehicle up and over to the normal ascent attitude and roll through 160°.

(c). Complete the remainder of the abort trajectory as though a normal ascent were being flown.

(5). Simulation results:

A complete tabulation of all terminal landing touchdown conditions is shown in Table 18. This table presents data for trials on which practice or baseline conditions were collected. However, it does not contain data on all trials given to the crew. The $\dot{x}$ data presented was obtained not from direct pilot control of $\dot{x}$ error, but from the geometric relationship between $\dot{h}$ and $V \cdot \left(\gamma = \sqrt{\dot{h}^2 - \dot{x}^2}\right)$.

Examination of the tabular data and corresponding results as shown in Figs. 39 through 51, indicates some rather interesting trends. After the initial learning period had passed, (defined as being the first 10 landings) and acceptable terminal conditions had been achieved in a somewhat repeatable fashion, significant layoff periods between flights resulted in a possible "forgetting" of the particular landing technique by the pilots. The terminal $\dot{h}$ and $\dot{x}$ plots for Pilots

Table 18 - Lunar Landing Performance Results

Trial	Pilot	$\dot{X}$ Ft/Sec	$\dot{Y}$ Ft/sec	$\dot{\theta}$ °/Sec	$\dot{\phi}$ °/Sec	$\dot{\psi}$ °/Sec	θ_E Deg.	γ_E Deg.	ψ_E Deg.	V_f Ft/Sec	$\dot{X}$ Ft/10^{-4}	% Fuel Used	Remarks
61	A	5.3	3.8	0.89	--	--	- 1.58°	49.0°	48.0°	--	--	-	Excursion
65	A	-2.5	3.73	-0.3	--	--	67°	- .3	-57.2°	--	--	-	"
66	C	-25.5	18.1	-0.24	--	--	67°	-13.7°	- 3.13°	--	--	-	"
67	C	-1139	133.3	-0.24	--	--	55.8°	- 6.68°	1.15°	1140	104.8	-	"
68	C	-295.7	13.06	-0.24	--	--	50.4°	-6.0°	- 5.06°	295.3	75.6	-	"
69	C	-319.5	9.07	-0.24	--	--	49.4°	-5.17°	4.16°	--	--	-	"
70	B	-1703	0	-0.65		--	0.68°	-2.92°	3.6°	1704	100.2	-	"
71	B	-1542	11.67	-0.24	--	--	-1.64°	-2.93°	-0.92°	1543	109	-	"
72	B	-3.6	3.47	-0.24	--	--	1.94°	0.5°	2.08°	4.6	61.18	-	"
73	B	-6.5	7.67	-0.30	--	--	2.28°	-6.82°	0.56°	9.8	60.85	-	"
74	B	-1.3	2.4	-0.8	--	--	4.18°	2.46°	-1.68°	2.47	60.52	-	"
107	B	-36	20	0.13	1.35	0.05	7.29°	4.64°	-3.31°	42.6	61.44	-	"
108	B	-5.8	3.66	0.24	-0.41	-0.48	1.75°	16.7°	-0.75°	7.3	61.21	-	"
109	B	-17	15.33	0.146	-1.85	0.412	-2.03°	9.58°	-1.22°	23.3	60.15	-	"
111	B	-54.2	26.3	0.387	-1.32	-0.056	-12.55	7.15	-3.65	60.9	62.59	-	"
112	A	-127.4	20.87	1.63	-5.39	-0.066	18.57	-3[illegible].2	-3.08	130.3	62.86	-	"
113	A	-42.[illegible]	15.53	0.053	-1.3	0.411	0.75	3.87	-1.95	46.1	64.23	-	"
114	A	-36.7	19.0	0.296	2.14	-0.46	-2.28	5.68	-0.12	41.9	61.62	-	"
115	C	- 0.6	0.93	0.529	2.07	-0.06	8.35	18.58	-0.91	1.73	70.68	-	"
117	C	-43.9	3.4	0.11	-0.14	-0.14	64.6	2.78	-2.97	44.67	66.57	-	"
118	C	-49	13.26	-1.84	0.33	-0.067	-1.3	20.93	-1.47	51.67	66.83	-	"
119	C	-12.3	16.8	0.065	0.789	0.06	-3.17	-6.52	-2.36	21.67	65.96	-	"
120	C	-44.3	70.0	4.87	0.716	-0.343	15.3	-53.3	-1.06	83.6	66.46	-	"
147	A	2.8	70.0	0.169	-4.85	-0.36	63.1	10.3	-1.39	7.67	66.63	-	"

Table 18 (cont'd)
Lunar Landing Performance Results

Tri al	Pilot	$\dot{x}$ Ft/Sec	$\dot{h}$ Ft/Sec	$\dot{\psi}$ °/Sec	$\dot{\theta}$ °/Sec	$\dot{\phi}$ °/Sec	θ_a Deg.	ψ_a Deg.	ϕ_a Deg.	V_c Ft/Sec	χ Ft/10^{-4}	% Fuel Used	Remarks
148	A	-62.1	19.27	0.011	0.60	0.10	58.9	1.0	-1.1	64.6	67.62	--	Excursion
149	A	-19.6	11.47	0.127	-3.02	0.014	-7.2	5.09	0.657	22.8	67.44	--	"
150	B	29.4	21.46	0.287	2.89	0.079	68.54	0.09	-3.37	36.73	67.46	9[illegible]3	"
151	B	8.0	5.8	-2.38	1.09	-0.041	-2.29	4.89	-0.697	9.93	66.59	101.[illegible]	"
152	B	1[illegible].6	1[illegible].4	-0.129	0.568	1.07	60.0	0.426	-1.5	21.00	66.56	101.4	"
153	C	3.3	52.13	0.290	0.992	0.075	19.2	7.70	-2.22	51.5	66.03	92.1	"
154	C	6.1	14.4	-0.283	-2.27	-0.328	0.277	2 .70	-2.24	15.73	65.65	103	"
155	C	-2.8	57.47	-1.87	0.837	0.148	2.2	11.8	-1.44	57.6	65.74	98.2	"
156	C	2.0	10.53	0.467	-0.312	0.145	55.31	-5.36	-0.69	11.0	65.49	96.1	"
160	A	29.1	40.47	-0.29	1.05	-0.719	29.05	-5.55	-0.234	50.13	61.94	88.1	Main
161	A	11.2	8.13	-0.168	-0.132	0.882	1.06	-4.68	1.37	14.07	60.89	102.6	"
162	A	9.0	6.73	0.543	0.849	-0.458	-0.182	-2.76	0.533	11.53	62.20	108.1	"
163	A	7.7	5.93	0.438	0.157	-0.35	-2.26	3.22	-2.46	10.20	62.55	97.9	"
164	C	8.4	6.0	-0.25	0.915	-0.049	0.875	-77.35	-0.95	10.4	60.13	94.6	"
165	C	3.3	2.27	-0.25	-1.37	-0.012	-4.09	-78.7	2.44	4.13	60.30	95.1	"
166	C	19.2	13.8	-0.25	0.068	-0.578	2.0	-6.8	-2.26	23.73	59.91	93.6	"
167	C	5.7	4.07	-0.25	-0.539	-0.242	-1.26	-0.88	2.13	7.07	60.39	95.9	"
168	C	4.4	3.07	0.052	-2.69	-0.349	2.0	1.08	6.38	5.53	60.50	93.4	"
169	B	11.8	8.47	0.048	-1.31	0.813	-0.58	-3.02	-0.56	14.73	59.54	98.1	"
170	B	8.5	6.13	-0.234	0.856	-0.068	-1.55	-2.86	-1.09	10.53	59.78	98.1	"
171	B	8.1	5.73	0.019	-0.264	-0.615	1.56	0.668	5.93	9.93	59.55	95.6	"
172	A	-6.8	3.93	-0.044	0.989	-0.267	-1.49	0.628	-1.26	8.0	60.15	97.6	"
173	A	7.8	5.6	0.071	2.01	-0.61	-1.93	0.40	2.06	9.67	59.54	93.7	"
174	A	-20.8	3[illegible].06	-0.96	4.63	-1.57	-14.50	-6.21	1.37	37.6	59.57	87.9	"
175	A	8.7	6.2	0.16	0.534	-0.085	-2.33	-2.76	-0.824	10.8	59.42	97.6	"
205	C	17.5	12.4	[illegible].048	-1.65	-6.28	04.2	5.27	3.46	22.1	63.99	101.4	Excursion

Table 18 - Lunar Landing Performance Results

(cont'd)

Trial	Pilot	$\dot{X}$ Ft/Sec	$\dot{h}$ Ft/Sec	$\dot{\psi}$ °/Sec	$\dot{\theta}$ °/Sec	$\dot{\phi}$ °/Sec	θ_c Deg.	ψ_a Deg.	ϕ_a Deg.	V_f Ft/Sec	X_{-4} t/10	% Fuel Used	Remarks
Flt. I-1	A	1.00	5.53	.232	.731	.503	-2.0	-.551	1.70	5.93	62.90	95.6	Main
-2	B	9.20	6.53	-.25	-.27	.66	-4.83	.464	-3.55	11.47	61.26	100.4	"
-3	C	-12.00	15.73	-1.02	-.081	.248	6.08	10.03	-.659	20.2	65.10	103	Excursion
-4	B	-13.1	7.8	.02	-.57	-.16	2.36	-2.22	-1.71	-15.07	67.05	94.1	"
262	B	6.1	4.6	.340	-1.75	-.503	5.76	-.718	-.538	7.93	61.29	86.9	Main
305	A	109.9	8.14	.68	3.87	.463	-19.05	1.04	-7.47	137.54	60.76	95.1	"
306	A	75.4	57.27	-.93	5.10	1.61	-22.0	2.69	4.83	95.27	61.29	94.1	"
307	A	-2.1	0.6	-.13	.365	-.089	.756	.279	-.189	-2.33	59.95	104.6	"
308	A	32.8	25.67	-.02	.327	-.693	-2.2	.956	1.21	43.27	59.53	94.1	"
314	B	10.1	7.6	-.24	-1.74	-.291	-3.5	.047	2.04	13.27	59.21	104.1	"
315	B	6.0	4.53	-.077	-1.87	-.015	-1.8	.047	.844	8.07	59.29	123.9	"
Flt. II	A	1.90	1.33	.12	1.16	0	-1.8	.745	.434	2.87	64.87	124.1	Main
"	B	A B O R T											"
"	A	5.00	5.50	-.34	-1.94	.07	-2.6	-4.3	-.55	7.93	88.54	102.1	Excursion
"	B	9.30	7.13	.46	1.27	.01	4.21	-.01	-2.02	12.07	78.15	102.8	"
319	B	-99.7	-176.2	.276	6.81	-.88	22.3	1.78	4.10	199.3	71.80	94.9	Excursion
320	A	-113.8	10.53	-4.04	1.88	.28	12.6	-2.0	1.28	115.6	71.67	96.6	"
321	A	-6.3	7.93	1.39	-2.78	.078	1.67	0.75	1.13	-7.93	71.74	94.9	"
323	A	11.9	22.10	.37	.262	.155	1.44	4.67	0.398	15.3	72.03	99.0	"
324	A	25.1	32.30	.50	5.53	1.06	2.93	2.16	1.78	31.9	71.00	96.1	"
366	C	13	13.86	.081	.021	.025	3.47	.203	+1.07	19.67	61.53	85.0	"
367	C	25.3	19.60	-.090	.381	-.045	2.80	-1.10	-.705	32.20	60.40	81.7	"
368	C	66.0	4.60	-.024	0094	.057	0.67	.636	-.31	8.13	68.80	81.8	"

Table 18 - Lunar Landing Performance Results

(cont'd)

Trial	Pilot	$\dot{X}$ Ft/Sec	$\dot{h}$ Ft/Sec	$\dot{\psi}$ °/Sec	$\dot{\theta}$ °/Sec	$\dot{\phi}$ °/Sec	θ_s Deg.	ψ_s Deg.	ϕ_s Deg.	V_f Ft/Sec	X Ft/10^{-4}	% Fuel Used	Remarks
369	B	7.9	5.93	-.038	.581	-.038	-.112	-1.32	9.93	9.93	61.05	88.6	Main
370	B	7.9	5.93	.035	.393	.026	-1.50	.342	-.741	10.07	60.87	89.4	"
371	B	6.5	4.80	.287	-.247	.019	0.54	.32	-.243	8.33	60.74	90.0	"
372	A	5.4	4.07	.241	-2.39	.050	5.15	.038	1.52	7.00	60.60	97.8	"
373	A	5.1	3.73	.043	.236	.013	-.38	.203	.045	6.67	60.79	91.7	"
374		8.8	6.66	.442	-.248	-.183	-1.7	.142	-1.24	11.27	60.78	90.6	"
375	A	A B O R T											
376	C	1.2	16.93	-.236	4.77	-.423	21.13	-	-	-17.26	75.67	90.0	Excursion
377	C	-40	2.33	1.043	.993	.016	24.52	-	-	48.93	76.21	89.5	"
378	"	2.0	19.2	1.58	-2.04	.082	12.3	9.3	.027	19.55	72.51	86.8	"
379	"	4.1	4.0	.065	-.53	-.398	3.84	-5.7	-2.23	6.6	72.6	90.8	"
380	A	1.0	14.59	-.254	-1.92	-.262	3.6	-7.87	-1.8	16.2	72.24	86.9	"
381	A	4.2	7.4	-.14	.533	-.322	3.42	-.84	-1.21	8.67	72.94	84.5	"
382	B	10.1	7.6	.091	.858	.160	3.9	.77	-1.06	12.9	72.45	89.7	"
383	B	10.3	8.0	-.08	.447	.40	2.61	-1.58	-1.36	13.4	71.72	86.4	"
384	B	A B O R T											
385	C	A B O R T											
Flt. 3-1	C	4.50	3.7	.077	-2.25	-.008	-.252	.864	-.944	5.93	61.13	82.0	Main
-2	B	A L O R T											"
-3	A	5.50	4.20	.012	0.067	.042	2.32	.24	.063	7.4	63.12		"
-4	C	-3.20	15.95	-.392	-5.39	.298	12.05	-.762	-1.61	16.3	73.49	85.1	Excursion
-5	B	-57.7	7.06	.40	0.207	-.162	-1.03	-1.34	-3.14	58.0	75.91	91.3	"
-6	A	8.0	8.35	.064	-.526	.837	2.66	-3.44	-.472	11.8	71.78	99.1	"

"A" and "B" demonstrate this phenomena remarkably well (Figs. 39 and 40). However, it is not as evident in Pilot "C's" performance (Fig. 41). The initial proficiency was quickly regained, however, usually after two "practice" landings. As a result of this retention lapse the first two practice landings for each pilot following Flights I and II were not assumed as representative "baseline" data.

It should be pointed out, that this "forgetting" tendency was not as obviously manifested in the three to four day interval between baseline and actual flight landing operations. It appears from review of the data as though the layoff period must be at least greater than one week before performance begins to show obvious changes. This factor could be of significant importance for prolonged flights and, therefore, some type of in-flight practice might seem advisable.

The total amount of fuel used for each landing by each pilot is shown in Figs. 42, 43, and 44. These plots are of interest inasmuch as two of the three pilots show a rather well defined learning curve. The high spikes appearing between Flights I and II should be disregarded inasmuch as an undetected fuse failure in the servo drive package functioning to provide mass and inertia changes caused these particular group of landings to be performed with a constant thrust-to-weight ratio. This, of course, required more fuel to accomplish than the same task with the mass changing as a function of thrust level. The crew adjusted well to this rather drastic change in vehicle dynamics and produced terminal conditions in the majority of the practice runs that were comparable to those obtained with the varying mass. This further indicates the high performance of the crew since no actual fuel meter was available during and prior to Flights I and II.

In the process of adjusting the thrust level to compensate for the increased mass, a new nominal throttle setting was marked by

the crew on the excursion vehicle's throttle plate. As was generally the case, during the first excursion landing, Pilot "A" moved the throttle to the marked position with the intention of varying the thrust level about this nominal. Before the beginning of Flight II the blown fuse was found and replaced returning the vehicle dynamics back to normal. Fig. 52 is a reproduction of the actual recorded velocity altitude profile flown by Pilot "A". Note the adjustment of the profile (knee in descent curve) as he sensed a too high rate of descent and the subsequent excellent terminal conditions achieved.

Prior to Flight III no fuel gauge was available in either the main or the excursion vehicle so that all tabular data concerning fuel used should be considered with caution. After completion of Flight II a gauge was added to the main ship to provide the crew with a readout of the last 20% of fuel remaining. No significant change in either landing technique or accuracy was noted although a somewhat smaller fuel use was used.

Figs. 45 through 51 provide both a cumulative picture as well as individual breakdowns of the baseline terminal conditions for both the main ship and the excursion vehicle. Examination will show that the crew, in general, controlled both the vehicle displacements and rates at touchdown to within reasonable limits. The touchdown altitude rate and range rate plots show a somewhat higher average than would normally be desirable, however, it is believed that this results from the physical limits of the display hardware and not from any crew deficiency. Even so, comparison of the baseline touchdown conditions with a representative set of landing gear structural limits (Fig. 53) will show that a large majority of all flights could be considered "safe" landings. Nevertheless, because of the intrinsic nature of the flight-display landing-technique relationship and because most of the display and scan pattern deficiencies would normally be rectified in any flight hardware, this data does not quality to be used for design purposes. The simple compari-

son between baseline and flight data to determine degradation is its only meaningful application.

A comparison between the main and excursion vehicle touchdown conditions is shown in Fig. 45 for all baseline data. A typical pilot comparison is shown in Fig. 46. Here again, it is believed that a great deal of the difference in terminal accuracy can be attributed to a relatively poor scan pattern in the excursion vehicle coupled with a limited altitude rate meter. This comparison demonstrates the strong effect of instrument layout and accuracy on the landing results.

One other point which deserves mention in regard (Fig. 46) is the large amount of cross-talk between the pilot commander and the navigator during a landing with the main vehicle. In general, the commander concentrated primarily on the CRT and 3-axis ball displays while the navigator kept him informed with regard to altitude and altitude rate readouts in addition to reminding him of normal landing procedures. This division of duties effectively reduced the scan problem existing with the main vehicle and was a natural selection by the crew.

(6). General comments:

Four landings were made in the initial flight (Flight I): two with the main vehicle and two with the excursion vehicle. During the two remaining landings aborts were called.

Three of the landings were completed with attitude rates at touchdown less than 10 fps with the fourth (Flight I-3) exhibiting marginal characteristics. The combination of the 10° yaw error and the comparatively high terminal altitude rate (15.73 ft/sec.) of the fourth landing would most likely result in an unsatisfactory landing. Examination of the landing averages (all flights) shown in Table 19 indicates that this high value for $\dot{h}$ is actually close to Pilot "C's" average for all baseline data. Pilot "C", in the excursion vehicle, demonstrated a difficulty in adequately con-

Table 19 - Lunar Landing Flight Averages

PILOT	VEHICLE	$\dot{h}$ FT/SEC	$\dot{x}$ FT/SEC
A	Excursion - 2 trials	6.93	6.50
"	Main - 3 trials	3.67	2.80
"	Average Overall - 5 trials	4.97	4.28
A	Average All Baseline	11.50	8.50
B	Excursion - 3 trials	7.32	26.70
"	Main - 1 trial	6.50	9.20
"	Overall Average - 4 trials	7.12	22.30
B	Average All Baseline	7.30	8.80
C	Excursion - 2 trials	15.80	7.60
"	Main - 1 trial	3.27	4.50
"	Overall Average - 3 trials	11.64	6.57
C	Average All Baseline	12.20	8.75

trolling the yaw axis of the vehicle throughout early practice and to some extent during baseline runs as well. This difficulty is attributed, in part, to the yaw bias contained within the control system.

Inadequate control of yaw was also demonstrated during the main vehicle aborted landing of Pilot "C". An abort signal was given at approximately 2500 ft. of altitude when the vehicle velocity had been reduced to about 330 ft/sec. Pilot "C's" reaction was to increase the thrust level of the vernier engines, cut the J-2 landing engine and then ignite the service module verniers and main engines. Inasmuch as he failed to cut the landing module verniers before he ignited the service module verniers (ignition of the service module verniers automatically separates the landing module), improper separation and possibly collision between the two stages would most likely have resulted. As the required roll-over maneuver was completed the yaw axis of the vehicle drifted with approximately a 55 degree error being present for almost 4 minutes, probably due to difficulty in interpretation of the reading on the 3-axis ball when the vehicle was pitched through greater than 90°. However, near the end of ascent, the error was realized and corrected.

The procedural error is best explained as a result of inadequate training, especially in those areas where the dynamic control tasks are intimately linked with the procedural tasks. During much of the pre-flight testing no attempt was made for repeated practice of the pilot's exact task, insofar as flight procedures were concerned, because of the limited training time available.

Inasmuch as the abort with the main vehicle was essentially a surprise, as far as the crew was concerned, a short period of time was taken by each crew member to pick up the specific task assigned during an abort operation. Since the abort was called because of a simulated electrical malfunction, the Engineer's first

reaction was to immediately hit the switches controlling the non-essential electrical busses throwing the capsule into complete darkness at a very critical time in the pitch-up maneuver. The error was quickly rectified by activating the emergency lighting switch which should have been activated before the buss switches were thrown.

The abort simulated during the second excursion vehicle landing was called at approximately 4000 feet altitude when the velocity had dropped to approximately 300 ft/sec. The subsequent recovery was well executed and a normal ascent completed with excellent terminal conditions.

The two excursion and single main vehicle landings made by Pilots "A" and "B" during Flight II had good touchdown conditions. Velocity-Altitude plots of Pilot "A's" landings are shown in Figs. 52 and 54. The large differences in the velocity-altitude profiles were due primarily to the aforementioned erroneous initial throttle setting for the excursion vehicle. The recovery, however, was well executed as is shown, and the flight was terminated with comparable touchdown conditions.

The second main vehicle landing (Pilot "B") was aborted 181 seconds after braking ignition when the vehicle was approximately 3000 ft. above the surface and had a velocity of approximately 650 ft/sec. The abort procedure was executed correctly except for one slight error. The landing module verniers were cutoff at 183 seconds and at 184 sec. the main J-2 engine was chopped. This was actually the reverse of the normal shutdown procedure inasmuch as the landing module verniers supply pitch-yaw attitude control. The fact that no pitch-yaw control, other than that obtained with the small reaction jets, was available during the shutdown of the J-2 was potentially dangerous because of the likelihood of shutdown transients. This was the only error in an otherwise perfect abort recovery.

The second excursion vehicle landing by Pilot "B" was executed correctly and was terminated with touchdown conditions very close to his average determined during baseline runs.

There were two main landings, one main landing abort, and three excursion vehicle landings simulated during Flight III.

The first main landing performed by Pilot "C" was in general well executed as shown in the velocity-altitude profile in Fig. 55. Again, however, he did not follow the correct engine ignition sequence inasmuch as he ignited the main J-2 engine before igniting his vernier engines. Furthermore, when the J-2 was cut in preparation for the terminal pitch-over he also cut his landing module vernier engines leaving only the attitude jets for control of the inevitable shutdown transients from the J-2. He apparently recognized his mistake after two seconds and re-ignited his verniers. A check of preflight data indicates that the proper propulsion sequencing was demonstrated with respect to both ignition and shutdown procedures for all baseline data.

Pilot "C's" excursion landing (see Fig. 56) was completed with an altitude rate of almost 16 ft/sec. This value is higher than the average observed during the baseline landings. In addition, an extremely large yaw error (almost 50°) built-up as the terminal pitch-up was executed. The yaw error persisted for almost 60 sec., and finally, was removed just before touchdown. In addition to the relatively high touchdown rate ($\dot{h}$) the vehicle's pitch error of 12° and pitch rate of -5.4°/sec. were considered excessive. This landing had to be classified, therefore, as unsuccessful.

The reasons for this failure are debatable. Pilot "C" had shown a difficulty with yaw control during the landing operations throughout the practice and baseline collection periods, as well as during Flight I. It has been shown in this flight, however, what is considered to be a definite degradation in retention of important

procedures. There is some evidence (see Figs. 41a and 41b) which indicates that Pilot "C's" terminal conditions were not sufficiently good prior to the flights in both the main and the excursion vehicles. The fact though, that landings were successfully completed in the pre-flight runs with the correct procedural sequencing, supports the theory of a decrease in proficiency through forgetting during the present flight.

The second main landing (Pilot "B") was aborted 176 sec. after ignition of the vernier engines when the vehicle was approximately 3500 ft. off the surface and traveling at 1150 ft/sec. A velocity-altitude profile of the barking and subsequent abort phase is shown in Fig. 57. A normal abort procedure was followed after which a normal ascent routine was entered. The only anomaly occurring during the abort routine was an initial roll in the wrong direction which was quickly reversed.

Pilot "B's" excursion landing (Fig. 58) was well executed except for an abnormally high range rate ($\dot{x}$) at touchdown (-57.7 ft/sec.). Since he did not have $\dot{x}$ error displayed properly, this result is understandable. Post-flight discussion with Pilot "B" indicated an awareness of the error in range rate during the final descent but did not know the direction in which the vehicle was moving (increasing or decreasing range) inasmuch as he neglected to observe his total velocity readout while going through the pitch-up maneuver. Rather than chance a further increase by controlling vehicle attitude without knowing the polarity of $\dot{x}$, he chose to ignore range rate and concentrated on altitude rate. His terminal $\dot{h}$ for this landing was average. It should be noted the range rate control was not one of the crew tasks.

Pilot "A's" main ship landing was well coordinated. The touchdown conditions as detailed in Table 18 indicate better than baseline averages. With the exception of the improved touchdown conditions this run was very similar

to those flown during baseline practice. The landing with the excursion vehicle was also well executed. A six channel recording record is shown in Fig. 59 to indicate typical parameter variations during an excursion landing.

In general, the performance of the crew during the lunar landing phase was extremely good and showed little variation from baseline trials. Certain procedural errors occurred which were coupled with the flight control tasks. These errors appear to be due in most cases to poor training which accentuated "forgetting" of task components. The performance of Pilot "C" is considered to be somewhat poorer than Pilots "A" and "B". However, this is believed to be due to the lesser amount of training time received by Pilot "C" as compared to Pilots "A" and "B" which increased the forgetting of procedural tasks. Pilots "A" and "B" participated extensively in setting up the simulation tasks thereby gaining more initial experience.

g. Lunar ascent:

An ascent from the lunar surface to a 100 n.m. altitude parking orbit was scheduled to be performed on each flight by each crew member using both simulators. The velocity error at orbit insertion and the integrated root sum square attitude error during ascent were recorded as a measure of pilot performance. This data is listed for the baseline runs and the three flights in Table 20.

The primary instrument used in this phase was the CRT. The display for Flights I and II was the same as that used in the translunar insertion phase: a pitch and yaw error indication in the center of the screen and velocity increment scale on the left of the screen. The velocity required for insertion was 5330 fps. This meant that to cutoff at the correct velocity, the pilot had to visually interpolate between a mark at 5000 fps and 7500 fps. After Flight II, when the digital velocity meter was installed, the velocity errors were reduced by more than an order of magnitude as can be seen from Table 20.

A programmed pitch attitude was followed during this phase. Subsequent to Flight I, noise was added to the pitch angle error signal on the CRT.

Table 20 shows that on Flight I, Pilot "A" had larger errors in velocity and attitude than any of the pre-flight baseline data, and the performance of Pilot "B", while comparable to the baseline, was somewhat worse. Pilot "C" had smaller errors than the baseline data.

On Flight II, Pilot "A's" performance was again considerably worse than the baseline data. Pilot "B", however, showed only a slight increase in the integrated root sum square attitude error, and the velocity errors were about the same as the baseline. The "noise" in the pitch error signal did not noticeably increase the errors.

The integrated root sum square attitude errors were recorded during the pre-Flight III baseline trials only for Pilots "A" and "B" in the excursion simulator because the data for the other trials were unusable. Comparing Flight III with the available data illustrates that the attitude errors in Flight III were much larger than those of the previous trials, while the velocity errors were much smaller. In fact, Pilots "A" and "B" had no velocity error in either simulator during this phase.

Summing the results obtained from the three flights, it was noted that the attitude errors were generally greater for the flights than for the preceding baseline runs. The velocity errors in Flights I and II were larger than the corresponding baseline runs due to the poor display. The poorer attitude control may be explained in a number of ways. First, the crew experienced a degradation in performance. The second is that in the period between the baseline runs and this phase in the Flights some forgetting of technique occurred.

The first of these possibilities did not seem probable. In subsequent phases there was no general performance degradation noted. And the velocity errors, although quite large in the first two flights, were not unreasonable when the limitations of the display

Table 20 - Lunar Ascent Performance Results

Trial No.	Pilot	ΔV Ft/Sec	$\int e$	Remarks
176	A	-	1320	Main
179	B	-14.	144	"
180	B	69.	187	"
181	C	215.	1012	"
182	C	36.	284	"
183	C	-66.	250	"
184	A	-157.	687	"
185	A	-24.	450	"
186	B	148.	550	Excurs.
187	B	-43.	450	"
188	B	-25.	1050	"
189	C	0	1295	"
190	C	-30.	1270	"
191	A	-31.	1050	"
192	A	36.	775	"
Flt. 1-1	A	-416	1136	Main
1-2	B	-45	537	"
1-3	C	-152	692	Excurs.
1-4	B	-136	807	"
291	A	-96	265	"
292	A	-70	318	"
293	A	-15	202	"
294	B	310	490	"
295	B	95	385	"
296	B	11	424	"
297	B	-18	296	"
317	B	-366	319	Main
Flt. 2-1	A	-278	1217	"
2-2	B	- 4	A B O	R T L A N D I N G
2-3	A	198	950	Excursion
2-4	B	-106	588	"
356	B	9	Attitude data unusable	Main - Digital readout of V installed
357	B	-1		"
358	B	9		"
359	A	9		"
360	A	9		"
361	A	9		"
362	C	-1		"
363	C	-1		"
364	C	-1		"
386	C	5		Excursion
387	C	1		"
388	B	2	486	"
389	B	-10	163	"
390	A	24	-	"
391	A	2	405	"
Flt. 3-1	C	9	1089	ail
3-2	B	0	Abort.	"
3-3	A	0	1000	"
3-4	C	-5	1813	Excursion
3-5	B	0	1095	"
3-6	A	0	1608	"
ER -12693	90.			

system were considered. In Flight III, with the digital indicator, the velocity errors were very small. For these reasons, it was concluded, that some forgetting of "optimum" piloting technique for this phase occurred on each flight. This is confirmed to some extent by the landing data. Further, there appears to be a direct correlation between high performance and properly displayed information. It is apparently not only necessary for the information for the task to be present but it must be displayed in a useable manner for the pilot. Forgetting of task procedures may also be related to properly display information. Since tasks which are not sufficiently well learned tend to break down as a function of time, any variable which would detract from proper information useage would accentuate forgetting.

h. Rendezvous:

One rendezvous was performed by each crew member during each flight. The same set of initial displacements and rates were used for all rendezvous except the first five baseline runs. The same initial conditions on pilot performance would not have to be considered during the evaluation of the results.

Pilot performance was evaluated by noting the relative distance along the three axes between the two vehicles and the translation rates along these axes at the completion of the rendezvous. The excursion vehicle was assumed automatically attitude stabilized.

The pilot initially acquired the parent vehicle visually using a starfield background. Once the vehicle was aligned, the pilot turned his attention to the CRT which at this point presented a PPI radar indication of the main vehicle's relative location. The two axes of this presentation were horizontal distances in the plane of the orbit and normal to the plane. Once the target (main vehicle was centered on this sequence with the rates nulled, a finer look angle was selected. Relative vertical distance could be recognized when on this scale by the size of the displayed target (see Fig. 32). The target presentation became a circle which grew larger as the two

vehicles came closer together. The final portion of the rendezvous was accomplished by keeping the circle centered on the display as it grew larger. When the circle filled the scope, the rendezvous was complete except for the last 150 feet. Verbal guidance for range control was given at this point.

The results obtained for this phase are contained in Table 21. It can be seen from this table that, except for Pilot "C" in Flight I, the flight results were essentially the same as the baseline data. This indicated that there was no degradation in pilot performance in the rendezvous phase that could be attributed to the confinement. The invalid results obtained by Pilot "C" in Flight I was due to failure in the CRT.

The total impulse was also tabulated for each rendezvous. This was a relative measure of the fuel consumed during the rendezvous maneuver. It was anticipated that this would provide another factor that could be used to evaluate pilot performance. However, no correlation could be obtained between fuel consumption and final conditions - or even fuel consumption and time required for rendezvous. Fuel consumption varied more than 100% between some runs. The values obtained during the flights generally were higher than the baseline values.

During Flight III, the starfield projection became inoperative, and all rendezvous were made using the CRT display only. This was possible since during normal operation the CRT contains similar information as the starfield and is given to the pilot by the control room after the pilot had acquired the main vehicle. This apparently had no effect on the results obtained. A typical X-Y-Z plot, obtained for all rendezvous, is shown in Fig. 60. By use of a modified "Cavalier" projection, a "3-D" effect was produced which was very helpful in visualizing the actual trajectory flown between the two vehicles.

1. <u>Transearth insertion:</u>

Insertion into the transearth trajectory from the lunar parking orbit was performed only during Flight III. Since Pilot "B" was to command this

Table 21 - Rendezvous Performance Results

TRIAL NO.	PILOT	X FT.	$\dot{X}$ FT/SEC	Y FT.	$\dot{Y}$ FT/SEC	Z FT.	$\dot{Z}$ FT/SEC	IMPULSE LB/SEC	TIME MIN.	REMARKS
136	A	6.0	2.44	31.0	.81	23.0	30.61	-	-	x_i - 50,000, y_i - 50,000, z_i - 50,000
137	A	59.0	1.01	84.0	.58	34.0	31.39	-	-	" "
138	"	54.0	1.45	95.0	.50	82.0	2.93	-	-	" "
140	C	3.0	1.77	4.0	.50	4.0	1.43	-	16.05	" "
141	"	5.0	1.57	1.0	1.18	1.0	1.46	-	14.31	" "
142	"	4.0	0.49	1.0	0.59	7.0	0.46	119,933	15.25	x_i - 5,000, y_i - 30,000, z_i - 30,000 and y_i - 300 ft/sec
143	"	3.0	1.4	1.0	1.02	1.0	1.73	-	22.20	" "
144	B	6.0	1.62	1.0	1.44	5.0	1.48	179,018	21.35	" "
145	"	9.0	1.4	1.0	1.56	0	1.30	157,500	20.53	" "
146	"	10.0	1.26	2.0	1.88	0	1.96	193,530	20.02	" "
Flt 1-1	C	5.0	3.03	31.0	18.36	13.0	22.8	84,242	11.32	CRT Failure
1-2	A	5.0	.68	0	0.79	3.0	0.70	80,777	22.40	
1-3	B	9.0	1.17	0	1.02	2.0	0.11	127,665	18.20	
303	A	4.0	0.19	2.0	0.05	0	0.24	95,902	12.45	
304	B	1.0	0.27	2.0	0.08	0	0.97	111,477	12.30	
Flt 2-1	A	0.0	.93	3.0	0.54	0	2.21	89,021	-	
2-2	B	2.0	.73	2.0	0.44	0	1.15	122,227	-	
348	C	5.0	1.44	0	.93	30	3.45	156,000	22.2	
350	A	9.0	1.85	1.0	.76	0	1.76	119,000	13.9	
352	"	2.0	.59	1.0	.85	0	1.21	156,000	13.9	
353	B	4.0	1.54	1.0	.67	0	3.11	128,000	12.2	
354	"	2.0	.68	1.0	.50	0	1.16	100,500	13.0	
355	C	1.0	.5	1.0	.58	0	.68	99,000	19.3	

Table 21 - Rendezvous Performance Results

TRIAL NO.	PILOT	X FT	X FT/SEC	Y FT	Y FT/SEC	Z FT	Z FT/SEC	IMPULSE LB/SEC	TIME MIN.	REMARKS
Flt 3-1	C	2.0	1.17	3.0	.54	0	.80	96,000	-	Starfield Failure
3-2	B	4.0	.65	4.0	.71	0	2.45	101,800	-	
3-3	A	1.0	.50	5.0	.50	0	1.30	85,500	-	

flight, two practice runs by him of this phase were recorded as baseline data following Flight II. The two performance parameters recorded were the integrated root sum square of attitude errors and the velocity error at thrust cutoff. These values for the baseline runs and for Flight III are listed in Table 22.

The primary attitude reference was the CRT, where pitch and yaw angle errors were presented. There was no pitch program during this phase, so the pilot merely had to hold "zero-zero" attitude. The actual velocity increment was shown on the same digital meter used in the previous phases. The velocity increment required for insertion was 2989 fps.

Table 22 indicates that the performance in Flight III was not quite as good as the baseline data. The attitude error was somewhat, but not significantly higher, and the velocity error was twice as large. Inspection of the data from other phases showed that a 20% variation in attitude error was well within the normal distribution of baseline data, so it was believed that it was of no significance in this case. The large velocity error was caused by the Navigator. The Navigator monitored the velocity meter, and due to misreading this meter he gave the Commander the signal to cut the engines too soon. It appears that this error was due to the rapid change of the digital display and in the necessity of mentally relocating the decimal point on the display for adequate useage.

j. Re-entry and earth landing:

Re-entry was simulated only during Flight III. Baseline data was gathered one or two days prior to the flight, after a number of practice runs. Two parameters were used to measure pilot performance. First, the integral of the root sum square of the angular attitude errors was recorded to show how well the nominal attitude was maintained. Second, the time integral of the product "velocity x altitude error" was obtained to show how closely the nominal trajectory was followed. The altitude error was "weighted" by the velocity factor because deviations in altitude were much more significant at higher velocity than at lower velocity.

Table 22

Transearth Insertion Performance Results

TRIAL	PILOT	S_e	ΔV_e	
406	B	316	34	
407	B	321	1	
Flt. 3	B	381	-69	Cut-off Early

Table 23

Re-entry Performance Results

TRIAL	PILOT	S_e	SV_{h_e}	
393	A	10,616	47.92	
396	A	11,210	-	
397	A	14,125	46.07	
399	C	9,551	36.99	
400	B	6,657	24.75	Increased sensitivity of $\dot{h}_e$ on digital read-out.
401	A	5,693	21.86	
Flt 3-1	B	10,330	46.5	$\dot{h}_e$ = -.7
3-2	A	8,862	43.5	$\dot{h}_e$ = +.5
3-3	C	5,477	7.5	$\dot{h}_e$ = -.15

The altitude error rate was controlled by the vehicle roll angle, in order to correct an altitude error it was necessary to hold a roll angle different from the commanded value. The "trajectory parameter" was considered much more significant than the "attitude parameter", because of the fact that an attitude error had to be maintained to correct an altitude error.

The roll reversals were another factor to consider. To guide the vehicle laterally, four programmed changes in the direction of the commanded roll angle were used. These changes were quite large and were very rapid and the roll power of the control system was not sufficient to match this rate. Therefore, large attitude errors lasting for a short period of time were unavoidable. The relatively slow roll rate of the vehicle also resulted in altitude rate errors, which, as stated before, could only be controlled by maintaining a roll angle error. Fig. 61 shows a typical flight record of control parameters.

Because it was thought that the altitude error rate at exit would be integrated throughout the skip where the pilot could not control it, primary consideration was given by the pilots to hold this term as small as possible at exit. Even a small value integrated during the entire skip would result in a large error. It later developed, that the integration was not continued during the skip so that the primary effort was somewhat misdirected through faulty instructions by the experimenters during the initial entry. However, it should be noted that in order to obtain the right range in an operational situation, precise control had to be maintained over all parameters including $\dot{h}$ error and h error.

The results of this phase are summarized in Table 23. The flight results for pilots "A" and "C" were better than the baseline data, while those for "B" are somewhat worse. No significance is attached to Pilot "B's" results, since it is believed that this is within the natural variation of the pilot's performance level. The altitude error rates at exit were .5, .7, and .15 fps. These values are extremely small and approach the limits that could be read on the display. It can be concluded then that the

pilots could perform the re-entry control tasks very well at the end of the seven day mission, and that no performance degradation due to confinement was noted.

B. Navigational Tasks

A realistic navigation task was simulated during each of the three flights. This task required the crew to take star fixes with a Trisextant and record the data on a modified adding machine. The starfield was presented by projecting slides on a rear projection screen located above the capsule window. A total of ten slides was shown during the translunar phase of flight. Seven of these slides showed the earth against a star background, and the remaining three showed the moon. The earth and the moon were shown in their proper positions on the celestral sphere as seen from the spacecraft. These positions were determined for a launch date of March 25, 1968. The translunar trajectory was inclined 35° to the equator and 63° to the Moon's orbital plane.

Different landmarks and different stars were used for each navigation fix. Table 24 presents the times of the navigation readings and the stars and landmarks used.

The Trisextant is a Martin developed instrument that allows the navigator to superimpose two stars and a landmark. The trisextant used in the simulation consisted of three movable tubes enclosed in a housing fixed in the capsule (pointing out the window) (see Fig. 62). The images coming through all three tubes were focused on a single eyepiece. Each tube had two readouts: an azimuth and an elevation. The navigation task consisted of superimposing the two stars on the landmark and then entering the azimuth and elevation angles for each tube into the adding machine.

The data obtained from each navigation reading (3 azimuths and 3 elevations) was reduced to a single number to minimize errors due to star slide shift. This number (Σ) was the sum of:

1. The angle between star A and the landmark.

2. The angle between star B and the landmark.

3. The angle between star A and star B.

These three angles are the three sides of a spherical triangle whose corners are the two stars and the landmark.

Table 25 gives the values of Σ obtained from the preflight data and from all three flights. The preflight arithmetic means was computed from an average of ten readings (for each slide) performed by the pilots and Martin personnel. The probable error in a single reading was also computed from these data.

Table 24

Time of Navigation Reading & Landmarks Utilized

NAVIGATION READING	FLIGHT TIME (Hrs.)	LANDMARK	STAR A		STAR B	
Translunar						
1	2.0	Tip of Florida	Pisces	γ	Cetus	η
2	3.06	Tip of Florida	Pegasus	"A"	Pisces	ξ
3	5.0	Yucation Peninsula	Pegasus	ξ	Pisces	α
4	7.5	N.W. Edge of Gulf of Mexico	Aries	α	Pisces	β
5	15.06	Tip of Aleutians	Aquarius	ξ	Cetus	ξ
6	23.5	Tip of India	Pegasus	α	Pisces	ϵ
7	35.5	Center of Earth	Pisces	β	Cetus	θ
8	55.00	Copernicus	Orion	χ	Orion	γ
9	60.06	Euclides	Lepus	ξ	Taurus	ξ
10	62.0	Darney	Orion	β	Taurus	β
Transearth						
1	102.35	Darney	Orion	β	Taurus	β
2	104.65	Euclides	Lepus	ξ	Taurus	ξ
3	108.65	Copernicus	Orion	χ	Orion	γ
4	120.35	Center of Earth	Pisces	β	Cetus	θ
5	128.15	Tip of India	Pegasus	α	Pisces	ϵ
6	134.0	Tip of Aleutians	Aquarius	ξ	Cetus	ξ
7	140.35	N.W. Edge of Gulf of Mexico	Aries	α	Pisces	β

Table 25 shows that there are large differences between the flight and preflight data. Only 8 out of 32 flight readings fell within the probable error of the preflight mean. There are two major reasons for these differences. The first and most important reason was slide misalignment. The projector automatically changed slides on command from the control room. There were large tolerances on the slide pick-up mechanism, and since the projector screen was 10 feet from the projector, a small error in slide position produced a large error in star position. This condition grew worse as the projector was used, and an attempt was made to correct it between Flights I and II, and II and III.

The second major source of error was the lack of a crosshair or other reference in the Trisextant. This allowed the navigator to perform the superposition task anywhere in a certain field of view in the eyepiece. An attempt was made to reduce this error by fixing the position of the landmark tube. This was not successful because slide misalignment often required movement of the landmark tube. Thus, the large differences between the flight and preflight data should be attributed to the prototype sextant system rather than operator errors.

In general, the crew considered the navigation tasks realistic. However, exact numbers for measuring performance were not available because of the problems mentioned in the previous section. These problems could be eliminated in any future simulation by using a fixed starfield and a more sophisticated Trisextant.

C. Systems Management Tasks

As stated earlier in this report, a number of crew tasks were related to the management of on-board systems. The importance of these tasks in an actual system cannot be overemphasized. Improper checking of subsystem status, improper performance of procedures during all mission phases, and improper maintenance of the system could cancel adequate performance on the flight control or navigation tasks. If the crew can perform these tasks adequately for long periods of time, they also increase the reliability of the total system. It has been suggested in the literature review in Appendix A that these types of monitoring tasks are probably most sensitive to the effects of sensory deprivation or confinement. Further, as will be seen in the next section of this report, a large portion (over 60 per cent) of the total time is spent on these types of tasks.

The data to be presented will include performance results of the crew on the various flights on operating procedures, system and log checks, and maintenance troubleshooting.

1. Crew Procedures: The crew's performance on procedures associated with all three flights was extremely good. There was a general increase in performance particularly

TABLE 25

NAVIGATION PERFORMANCE RESULTS

NAVIGATION READING	PREFLIGHT ARITHMETIC MEAN Σ_1 (DEG)	PROBABLE ERROR IN SINGLE READING Σ (DEG)	FLIGHT I Σ_1 (DEG)	FLIGHT II Σ_1 (DEG)	FLIGHT III Σ_1 (DEG)
Translunar					
1	109.3	0.61	131.5	144.2	106.1
2	108.4	0.70	108.0	108.6	119.3
3	98.6	1.56	109.3	95.3	114.6
4	145.7	1.85	145.2	109.0	/
5	78.6	3.44	81.9	80.3	/
6	75.9	2.29	76.4	73.3	84.1
7	60.0	1.94	57.1	68.5	59.6
8	116.9	2.33	122.7	*	*
9	105.7	0.78	107.3	43.1	102.5
10	110.4	1.30	108.3	113.6	101.2
Transearth					
1	110.4	1.30	No transearth	No transearth	104.4
2	105.7	0.78	↓	↓	100.8
3	116.9	2.33			*
4	60.0	1.94			56.5
5	75.9	2.29			71.5
6	78.6	3.44			81.2
7	145.7	1.85			119.3

* Star Slide Badly Misaligned
/ Wrong Slide in View at Time of Fix

by Pilots "A" and "B" between Flight I and Flight III. This increase in performance was due to two factors: increased familiarization and revised crew checklists.

Although the crew learned the procedures fairly well, some procedural errors were made. Most of these errors were corrected at the end of the first two flights, or during Flight III. The following are examples of some of the errors made:

a. Failure to arm the separation bolts for a lunar landing abort.

b. Failure to extend the landing gear for a landing with the lunar excursion vehicle.

c. Failure to level the main vehicle after a lunar touchdown.

d. Failure to change the reference from "earth center" to "moon center" at the appropriate distance from the moon.

e. Failure to activate the radar altimeter at the appropriate distance from the moon.

f. Use of the incorrect mode of the inertial platform during the translunar trajectory.

g. Use of the minitrack beacon during an inappropriate mission phase (lunar orbit).

Some of these errors have already been discussed in a previous section as to their effect on flight control performance. The others, such as "d", "f", and "g" are considered minor procedural errors which are not time critical or could be corrected from the ground control or on the next crew systems check.

During each of the three flights, procedural errors were also made by control room personnel. These were also corrected and were greatly minimized during Flight III. It is believed that the occurrence of such errors by the control room demonstrates the natural occurrence of such errors over and above the effects of confinement and sensory deprivation. The only mode of combating the occurrence of these errors is by longer training periods in which both the flight crew and ground personnel overlearn these

routinized procedural tasks. However, we can definitely conclude that no specific effects on procedural tasks can be related to confinement or sensory deprivation situations as contained within the data reported in the present study.

2. Log and Systems Tasks: During the training period the crew was provided with systems check procedures and a log chart.

The systems check indicates the procedure for checking out the onboard subsystems at the flight panel. This check provides the crew with a more comprehensive evaluation of the overall system operation than can be ascertained from monitoring systems status alone. Furthermore, the detection of a marginal condition or failure is to some extent simplified by the performance of the systems check. The check involves switching from operational to backup equipment and checking performance, feeding signals to various subsystems and measuring outputs, and examining present system levels and projecting these ahead in time to predict future conditions.

In general, the systems check was performed prior to and after each major thrusting phase of the mission. This allowed the crew to ascertain the condition of the entire system prior to committing to another mission phase.

The log chart is a form used for periodic logging-in of detailed aspects of the onboard subsystems. That is, status of panel lamps, readings on all instruments and counters - such as quantities, temperatures, voltages and pressures, as well as "go" "no go" operational status, were recorded. This recorded information provided the means by which the crew could make comparisons between earlier and current readings. Another purpose of the log check was to provide a permanent record of logged readings as a function of time, which for an actual mission would be valuable for later analysis of the flight.

In general, the log check was completed approximately every four hours, and in some cases was completed in conjunction with a systems check.

To determine the accuracy of the crew in logging the various flight panel readings, a comparison was made between the crew logs, and logs taken simultaneously in the control room. The comparison indicated that during all three flights no crew errors were made, but that some readings were omitted in a few instances.

Table 26 indicates the average time required to perform the systems and log checks, with an indication of the number of men that performed the checks, for each of the three flights. It will be noted that the systems and log checks, when performed together, were always performed by two men. Initially, it was believed each of these tasks could be performed by one crew member. However, at the end of Flight I, crew comments indicated that systems and log checks were preferred and more accurate when performed by two crew members. Log checks when performed without the system check were still performed by only one crew member.

Table 26

Average Time for Systems and Log Checks

Flight	Log Check		System & Log Checks
	1 Man	2 Men	2 Men
I	16 Min	17 Min.	43 Min.
II	20	16	26
III	18	11	21

From the data contained within Table 26, it can be seen that the times required to perform the two-man log checks, and particularly the systems and log checks (performed concurrently), decreased substantially from Flight I to Flight III. This result seems to indicate that practice, and better procedures and techniques, were the factors which led to the increased proficiency in these tasks and that this learning and familiarization was not affected by the confinement environment. There was also no difference within each flight on the performance time. This would further indicate no effect from the environment on this type of performance.

It is believed that the one-man log check does not follow this pattern. It is likely that a major factor was that the Flight II crew was not identical to the crew of Flights I and III. The log check task also required a finite amount of time to perform adequately by one man. This was approximately 15 minutes. Therefore, the differences between the flights appear to be non-significant.

3. Troubleshooting: During each flight two types of preplanned malfunctions were introduced from the control room. One type of malfunction required that an adjustment be made at the display panel with maintenance being unnecessary or impossible, and the second type required that maintenance be performed utilizing the maintenance panel.

The preplanned malfunctions that were introduced are shown in Table 27. When a malfunction requiring maintenance had been located by an on-duty crew member, the off-duty crew member was alerted and then performed the troubleshooting-maintenance task. The instructions to the crew (during the training period) indicated that they were to assume that each malfunction occurred in a system of 30 testable and replaceable components, one, and only one of which had failed. These components could be tested, either one at a time or in certain combinations, by setting six rotary switches and making two patch connections. The instructions also indicated that the object of the task was to locate the failed component using the smallest number of tests, (i.e., in minimum time, since all tests take essentially the same amount of time to perform).

As indicated previously, the task was made somewhat realistic by the use of failure-rate data. The values used were:

Component	Probability of Failure
1-6	.082
7-15	.040
16-30	.010

After the failure had been located on the Maintenance Panel, the malfunctioned subsystem or component was returned to a "go" condition by the Control Room.

It was of particular interest to learn whether the crew utilized this probability information, and how their test sequences compared with an optimum (mathematical) strategy during the various flights and within each flight.

The data indicates that the crew did, in fact, use the probability information, and their strategy differed from the optimum by only about 1%. Further, there appeared to be no effect due to sensory deprivation or confinement. The crew had evolved a strategy prior to the mission that

Table 27

Preplanned Malfunctions

Flight I

a. High lunar module vernier engine temperature - adjustment required.
b. High vernier engine chamber pressure - adjustment required.
c. High internal wall and atmosphere temperatures - adjustment required.
d. Suntracker failure - maintenance required.
e. Environmental system: compressor failure - maintenance required.

Flight II

a. High lunar module main engine temperature - adjustment required.
b. Computer failure - maintenance required.
c. Electric power reactant flow malfunction - adjustment required.
d. Environmental system pump failure - maintenance required.
e. Tape recorder failure - maintenance required.
f. Landing gear extension malfunction - adjustment required.

Flight III

a. High internal wall and atmosphere temperatures - adjustment required.
b. Computer malfunction - maintenance required.
c. Toxic gas - adjustment required.
d. Computer malfunction - maintenance required.
e. Inertial platform caging malfunction - maintenance required.
f. High lunar module vernier engine temperature - adjustment required.
g. Communications ranging system malfunction - maintenance required.
h. Space sextant: non-entry of time into computer - maintenance required.
i. Fire - adjustment required.
j. High vernier engine chamber pressure - adjustment required.
k. Electric power reactant mix malfunction - adjustment required.
l. Radar altimeter malfunction - maintenance required.

was apparently used by all crew members. The data demonstrated that this strategy was followed, except for the first failure in Flight III, which represents a clerical, or manipulative, error. The expected number of tests per failure, as computed from the crew's strategy and the given probability distribution is 4.93.

The optimum strategy (i.e., the strategy for which the expected number of tests per failure, subject to the given probability distribution, is minimum) is as follows:

a. Perform the tests containing six components in order of decreasing probability until a red light is obtained. The red light indicating the location of a failure in one of the modules tested.

b. Once the six component "module" in which the failure occurs has been located, perform single component tests within that module, in order of decreasing probability, until the failed component is located.

For this optimum strategy, the expected number of tests per failure is 4.87.

The behavior represented by this task was simple decision-making. The task itself became routinized by the crew's adherence to a strategy which they jointly developed. Therefore, rather than exploring the effect confinement and sensory deprivation stress on decision performance, this troubleshooting task developed into another set of procedures which the crew had to follow. This, in fact, made the troubleshooting task more realistic since on-board maintenance itself may be a routinized task based on strategies previously developed (Ref. 46). Therefore, no difference was noted between crew performance and their strategy and the optimum mathematical model in terms of the number of tests per failure. Further, performance on the adjustment maintenance tasks by the crew during all flights indicated no decrease in performance or speed of reaction. These data clearly indicate that performance on maintenance tasks as simulated in the present study were not affected by the confined environment.

D. Duty Cycle

The two duty cycles evaluated in the present study differed in a number of ways. The duty cycle for Flight I was a normal 24 hour repeatable cycle while for Flights II and III the cycle was a 26 hour re-

peatable cycle. Further, the Flight I duty cycle was less a departure from normal diurnal variation than the one used for the other flights. In Flight I, the crew was allowed 8 hours of uninterrupted sleep, 6 hours of relaxation or off-duty time, and 10 hours of work in a 24 hour period as opposed to two, 4 hour separate periods of sleep, 10 hours of work, and 8 hours of relaxation or off-duty time for Flights II and III. The following criteria for optimum duty cycles were applied to the design of each cycle:

1. Orientation to the mission tasks.

2. An off-duty period before and after a sleep period to avoid difficulties associated with performance upon awakening.

3. Duty periods of no longer than 2 hours except where necessary due to mission requirements.

4. A reasonably repeatable cycle except where mission or task requirements dictate deviations.

Tables 28 and 29 present the duty cycles used for Flights I and III. The duty cycle for Flight II will not be presented since it was the same as Flight III. The choice of which cycle to use for Flight III was based on the evaluation by the crew of the Flight I and II cycles. Since Flight III was a long duration mission, it was believed necessary to utilize the best cycle possible during this flight. The criteria given above for duty cycles were met most completely in Flight III. The major exception from realistic operational considerations was during the lunar landing and re-entry phases, in Flight I at 60 hours and in Flight III at 70 and 160 hours. This exception was due to the landings and re-entries made by each crew member which extended their duty times.

Table 30 presents the total amount of time spent by each crew member in different activities during Flight I. Inspection of this table indicates that time spent in the different work cycle periods for each crew member were very equal, and in most cases, the general ratio of duty to off-duty to sleep was fairly constant. The exception occurring as previously discussed during the lunar landing phase. Table 31 presents the same data for Flight III. Inspection of this table indicates that time spent in the different work cycle periods for each crew member was fairly equal. Further, the cycle was essentially repeatable each 26 hour period for each crew member. Perfect repeatability of duty cycles for long term missions appear unrealistic since the demands of the mission and the tasks themselves influence the periodicity of the cycle.

Other important parameters of the duty cycle for Flight I are as follows:

Table 28

Duty Cycle for Flight I

Time	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
C	d	d	d	d	d*	O^{R}	d	d	O*	O^{E}	d	d	d	O*	d
N	d	d	d	d*	O^{E}	d	d	O*	d	d	O*	S	S	S	S
E	d	d	d	d*	S	S	S	S	S	S	S*	O	d	d	d*

Time	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
C	d	O	d	d	S	S	S	S	S	S	S	S*	O^{E}	d	d	O*
N	S	S	S*	O	d	d	O*	d	d^{R}	O	d*	d	d	O	d	d*
E	O^{R}	d	O	d*	d	O^{E}	d	d*	O	d	d^{R}	O*	S	S	S	S

Time	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
C	d	d	O	d	d*	O	d	d	O*	d	dR	O*	S	S	S	S	S
N	O	d	d	O*	S	S	S	S	S	S	S	S*	O^{R}	d	d^{E}	O*	d
E	S	S	S	S*	O^{E}	d	d	O	d*	d	O	d	d	O*	d	d	O

Time	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
C	S	S*	O	d	d	O*	d	d	d^{R}	O*	d	O^{E}	d	d*	d	d
N	d	O	d*	d^{R}	O	d	d^{E}	O*	S	S	S	S	S	S*	d	d
E	d	d*	S	S	S	S	S	S*	O	d	d	d	O^{E}	d*	d	d

Time	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
C	d	d	d*	S	S	S	S	S*	d	d	d	d*	d	d	
N	d	d	d*	O	d	d	O	d*	d	d	d	d*	d	d	
E	d	d	d*	d	O	d	d^{R}	O*	d	d	d	d*	d	d	

C - Commander d - duty period * - urine sample

N - Navigator O - Off-duty period R - reaction time

E - Engineer S - sleep period E time estimation

Table 29

Duty Cycle for Flight III

Time	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
C	d	d*	d	d	d	d	*O^{R}	d	d	O	*d	d	^{E}O	*S	S	S	S	*O	d
N	d	d*	d	d	d	O*	d	d	O^{E}	*d	d	O	d	d*	O	d	^{R}O	*S	S
E	d	d*	d	d	O	*d	d	O^{R}	*d	d	O	d	d*	O^{E}	d	O	d*	d	d

Time	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
C	d	d	d*	O	O	d	d	*O^{R}	S	S	S	S	*O^{E}	d	d	O	*d
N	S$_{R}$	S	*O	d	d	O^{E}	*d	d	O	d	d*	O^{R}	S	S	S	S	*O
E	O	O	*S	S	S	S	*O	d	d	O^{E}	*O	d	d	O	*d	d	O*

Time	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
C	d	O	d	d*	O	S	S	S	S*	O^{R}	d	O	*d	O	O^{E}	d
N	d	d	O^{E}	*d	d	O	d	d*	O^{R}	S	S	S	S*	O	d	d
E	S	S	S	S*	O^{R}	d	d	O	*d	d	O	d	d*	O^{E}	S	S

Time	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
C	d*	O	S	S	S	S*	O^{R}	d	d	O	*d	d	O	d*	O	O^{E}
N	O	*d	d	O	d*	O^{E}	S	S	S	S	*O	d	d	O*	d	d
E	S	S*	O	d	O	*d	d	O^{R}	*d	d	d	.	S	S	S	S

Time	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81
C	*S	S	S	S	*O	d	d	d	d	d	d	*O^{R}	d	O	*S	S
N	d	O^{R}	*O	d	S	S	S	S	*O^{E}	d	d	d	*O	d	d	O*
E	*O^{E}	d	d	O	*d	d	d	d	d	*O^{R}	S	S	S	S	*O	d

Time	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
C	S	S	*O^{E}	d	d	d	d*	d	d	d	*O	d	O^{R}	*S	S
N	d	O^{R}	*S	S	S	S	*O	d	d	d	d	*O	d	^{E}O	O
E	O^{R}	*S	d	d	d	d	d	*O^{E}	S	S	S	S	*O	d	d

Time	97	98	99	100	101	102	103	104	105	106	107	108	109
C	S	S	*O	d	d	O^{E}	*d	d	O	d*	d	^{R}O	*S
N	d	O*	S	S	S	S	*O^{R}	d	d	O*	d	d	d
E	O	*d	d	O^{E}	d*	d	d	O	*S	S	S	S*	O^{R}

Table 29 (Cont'd.

Duty Cycle for Flight III

Time	110	111	112	113	114	115	116	117	118	119	120	121	122	123
C	*S	S	S	O	*d	d	O^{E}	*d	d	O	d	d*	O^{R}	S
N	O*	d	O^{E}	S	S	S	S	*O	d	d	O^{R}	*d	d	O
E	d	O	*d	d	O	d	d	$*O^{E}$	S	S	S	S	O	d

Time	124	125	126	127	128	129	130	131	132	133	134	135	136
C	S	S	S	*O	d	d	E_O	*d	d	O	d*	d	O^{R}
N	d	d*	O^{E}	S	S	S	S	*O	d	d	R_{O*}	d	d
E	d	O	*d	d	O^{R}	d*	d	O	S	S	S	S*	O^{E}

Time	137	138	139	140	141	142	143	144	145	146	147	148	149	150
C	S	S	S	S	*O	d	d	O^{E}	*d	d	d	O	*d	d
N	O	d	d*	O	d	E_O	*S	S	S	S	O*	d	d	O^{R}
E	d	d	O*	d	d	O	d	d	O	O^{R}	S	S	S	S*

Time	151	152	153	154	155	156	157	158	159	160	161	162	163	164
C	O	*S	S	S	S	$*O^{R}$	d	d	O^{E}	*d	d	O	d	d*
N	*d	O	d	d	O^{E}	*S	S	S	O^{R}	*d	d	d	O	O*
E	O	d	O^{E}	*d	d	d	O^{R}*	d	d	S	S	S*	d	d*

C - Commander

N - Navigator

E - Engineer

d - duty

O - off-duty

S - Sleep

* - Urine

R - reaction time

E - time estimation

Tabl 30

Different Activity Phases for Flight I

	Commander			Navigator			Engineer		
	Duty	Off-Duty	Sleep	Duty	Off-Duty	Sleep	Duty	Off-Duty	Sleep
0-23 hours	12	5	7	11	6	7	12	5	7
24-47 hours	10	6	8	10	6	8	10	6	8
48-71 hours	15	4	5	14	4	6	14	4	6
Totals	37	15	20	35	16	21	36	15	21

Table 31

Different Activity Phases for Flight III

	Commander			Navigator			Engineer		
	Duty	Off-Duty	Sleep	Duty	Off-Duty	Sleep	Duty	Off-Duty	Sleep
0-25 hours	14	7	5	14	8	4	14	8	4
26-51 hours	11	8	7	11	7	8	10	8	8
52-77 hours	11	7	8	11	7	8	13	7	6
78-103 hours	12	6	8	9	9	8	14	6	6
104-129 hours	11	7	8	12	7	7	10	8	8
130-155 hours	11	7	8	12	9	5	10	8	8
156-164 hours	6	3	0	3	3	3	5	1	3
Totals	76	45	44	72	50	43	76	46	43

1. The longest sustained waking periods for the Commander was 20 hours at the initial portion of the flight, for the Navigator 17 hours during the mid-portion of the mission, and for the Engineer 22 hours at the end of the mission.

2. The longest time periods of sustained duty for the Commander was 7 hours, for the Navigator 6 hours, and for the Engineer 7 hours. The average duty period for the Commander was 2.9 hours, for the Navigator 2.7 hours, and for the Engineer 2.8 hours.

3. There were three sleep periods for each of the crew members during this flight. On four occasions off-duty periods occurred immediately after the sleep period. On one occasion an off-duty period occurred immediately before a sleep period, and on one occasion no off-duty period occurred either before or after the sleep period.

4. The Commander had 15 off-duty periods, the Navigator had 16 off-duty periods, and the Engineer had 15 off-duty periods.

5. Table 32 presents mission time compared to the type of task the mission requires. It can be seen from this table that 21.1 per cent of the time was spent in actual flight control tasks, that 13.2 per cent of the time was spent in navigation tasks, and that 65.7 per cent of the time was spent in monitoring tasks.

The results of Flight I indicated no direct effect upon performance due to the duty cycle. However, all examiners reported that the crew appeared fatigued due to the lengthy hours of duty time at the end of the flight. Further, the crew indicated that they felt that long sustained duty periods in excess of four hours made the monitoring task difficult. They also stated that an off-duty period is definitely required after a sleep period and that the sleep periods were not utilized for the entire eight hours. The Engineer indicated difficulty in sleeping for 8 hours, two hours after lift-off. Since no preadaptation was given prior to the flight, the crew was on a normal sleep-wakefulness cycle at the start of the flight and the Engineer did not require sleep at this time. Crew comments further indicated no adaptation to the cycle during the 76 hours of the flight. Generally, this type of cycle was more difficult to adapt to the mission requirements and crew tasks.

Flight III was more than twice as long as Flight I and was certainly a more severe test of any proposed duty cycle. Some important parameters of the Flight III duty cycle were:

Table 32

Mission Time Versus Crew Tasks

Flight I

Mission Time Hours	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Crew Tasks	C	C	N	N	C	N	M	N	M	M	M	M	M	M	M	N

Mission Time Hours	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Crew Tasks	C	M	M	M	M	M	M	N	M	M	M	M	M	M	M	M	M

Mission Time Hours	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Crew Tasks	M	M	N	M	M	M	M	M	M	M	N	M	M	M	M	N	C	N

Mission Time Hours	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
Crew Tasks	M	M	M	M	M	M	M	M	C	C	C	C	C	C	M	M	M	M	M	M	C

Mission Time Hours	72	73	74	75
Crew Tasks	C	C	C	C

C - Control Task

M - Monitoring Task

N - Navigation Task

1. The longest sustained waking period for the Commander was 15 hours at the initiation of the flight, for the Navigator 19 hours at the initiation of the flight, and for the Engineer 23 hours at the initiation of the flight.

2. The longest time period of sustained duty for the Commander was 7 hours, for the Navigator 4 hours, and for the Engineer 6 hours. The average duty period for the Commander was 2.2 hours, for the Navigator 1.9 hours, and for the Engineer 2.2 hours.

3. There were 11 sleep periods for each crew member during Flight III. On 32 occasions an off-duty period occurred immediately before and after the sleep period. On one occasion the off-duty period occurred only after the sleep period.

4. The Commander had 43 off-duty periods, the Navigator had 47 off-duty periods, and the Engineer had 43 off-duty periods.

5. Table 33 presents mission time compared to the type of task the mission required. It can be seen from this table that for the 7 day complete lunar landing mission 16.4 per cent of the time was spent in actual flight control tasks, 10.3 per cent of the time was spent on navigation, and 73.3 per cent of the time was spent on monitoring tasks.

The results of Flight III indicate, as in Flight I, no direct effect upon crew performance due to the duty cycle. However, examination of the crew indicated no evidence of fatigue or irritability as found at the end of Flight I. During the crew debriefing, the crew stated that they were completely satisfied with the duty cycle, indicating that this cycle aided them in maintaining their performance during the monitoring periods. There were no indications by the crew that they had adapted to the duty cycle at the end of the seven day period. However, there was an indication of less fatigue during monitoring phases occurring in the early morning hours during the later portion of the flight.

The percent of time spent on various general categories of tasks which were presented in Tables 32 and 33 were, of course, dependent upon the specific experimental design used in the present studies. However, upon recalculation of the influence of the four extra landings and two re-entries performed in Flight III, it still appears that at least 65 to 75 per cent of the total mission time would be spent in monitoring and system management tasks.

Table 33

Mission Time Versus Crew Tasks

Flight III

Mission Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Crew Task	C	C	N	N	C	N	M	N	M	M	M	M	M	M	N	N	C	M	M	N	M	M	M	N	M	M	M	M

Mission Time	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
Crew Task	M	M	M	M	M	M	M	N	M	M	M	M	N	M	M	M	M	M	M	M	M	M	M	M	M	M	M	N	M

Mission Time	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Crew Task	M	M	M	N	C	N	M	M	M	M	M	M	M	M	C	C	C	C	C	C	M	M	M	M	M	M	M	C	C	C

Mission Time	87	88	89	90	92	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112
Crew Task	C	C	C	C	C	M	M	M	M	M	M	M	M	M	M	N	C	N	M	M	M	N	M	M	M	M

Mission Time	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135
Crew Task	M	M	M	M	M	M	M	N	C	M	M	M	M	M	M	N	M	M	M	M	M	N	M

Mission Time	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158
Crew Task	M	M	M	M	N	C	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	N	M

Mission Time	159	160	161	162	163	164
Crew Task	M	C	C	C	C	C

C - Control Task
M - Monitoring Task
N - Navigation Task

The data presented in the present results provide backup to some of the conclusions presented in the literature review in Appendix A. The present data further added impetus to these conclusions since it was obtained with realistic tasks and with a realistic time-mission-trajectory relationship. These confirming conclusions are as follows:

1. The crew appeared to follow the same 24 hour periodicity as they did prior to either Flight I and Flight III. There appeared to be no full adaptation to the 24 or 26 hour cycle but there were indications that the crew might be approaching an adaptation level in Flight III (Analyses of the corticosteroid data for Flight III, to be submitted in a separate report, might substantiate this). However, the crew did not subjectively report any detrimental effects of the 26 hour cycle.

2. The duty cycle utilized in Flight III was amenable to manipulation based upon the mission tasks and mission trajectory. The duty cycle for Flight I did not have this versatility and this caused the long hours of duty for each crew member noted at the end of Flight I. Other duty cycles, 4 on and 2 off (Ref. 31), also appear difficult to utilize with real mission tasks.

3. There were not any discernable performance effects due to either cycle. However, it is difficult not to consider the possibility of fatigue effects on performance during Flight I. The Flight III schedule indicated no fatigue effects.

4. The off-duty periods after the sleep period is quite necessary from the crew's point of view. This correlates highly with results of Langdon & Hartman (Ref. 33).

5. Two hour duty periods for the monitoring tasks during the coast phases are necessary in order to maintain high detection performance (Ref. 32). Two, four hour sleep periods appear sufficient and there were indications that two, three hour sleep periods may also be appropriate.

6. Since the crew was not preadapted to the duty cycle, no definitive data can be presented. However, there does not appear to be any discernable performance effects from not adapting to the duty cycles in Flights I and III by any of the crew members. Therefore, no evidence exists for the requirement of a preadaptation period from the data obtained in this study.

7. The data on duty cycle adaptation as indicated by the corticosteroid analyses for Flights I and II will be presented in the next section.

8. It should be noted that any effect on performance by the duty cycle might have been disguised by the high motivation and skill of the crew (Ref. 31). However, the subjective pilot reports indicated a preference for the Flight III duty cycle. It is, therefore, suggested that with highly trained and motivated astronauts less than idealized duty cycles are acceptable (i.e., 4 on and 2 off). Further, one of the most important parameters of the duty cycle is mission and task applicability rather than strict adherence to duty-cycle design.

E. Psychophysiological Inflight Measures

As discussed earlier in this report, a number of measures were obtained on crew performance or crew status on tasks not concerned with the operation of the system. These tasks could possibly indicate effects due to sensory deprivation and confinement not discernable from complex task performance, and further these tasks are somewhat similar to those utilized in the more basic studies described in Appendix A. The corticosteroid data to be presented has two implications. First, it is an indicator of crew reaction to stress, if stress exists, by an elevation of the corticosteroid levels as compared to baseline conditions. Second, it is an indication of adaptation to the duty-cycle since the normal levels of corticosteroids follow a diurnal pattern. Blood pressure data was also collected to indicate the occurrence of any stress throughout the flights.

Information is presented on crew diets and the effectiveness of the inflight exercise program in alleviating any confinement effects. Also the results of the medical and psychological studies are presented as they relate to each of the flights.

1. Behavioral response performance: The Behavior Response Panel was used to collect data pertaining to the effects of confinement and sensory deprivation on two tasks, which are described below. Both tasks were performed during off-duty hours, for a period of time not exceeding 8-10 minutes during any given off-duty period.

   The panel is depicted in Fig. 63. It should be noted that not all of the display components on the panel were used during this study, and only those aspects that were utilized will be discussed.

   A Standard electric clock, calibrated in seconds and hundred, was mounted on the upper right hand corner

of the panel. The clock "Start" - "Stop" pushbutton was located to the lower right of the clock. The clock and the pushbutton were used in conjunction with the Reaction Time task discussed below. The panel lamps at the center of the left hand side of the panel are labeled from 1 sec. to 5 min., and a "Start" - "Stop" toggle switch was mounted directly to the right of the latter panel lamps. The panel lamp and toggle switch were used in conjunction with the Time Estimation task, which is also discussed below. The bottom-center of the panel contains an "Are You Ready" lamp, a "Ready" pushbutton, and a "Go" lamp, which were used for both tasks.

a. Reaction Time - This was a typical reaction time task in which a clock on the Response Panel was started (from the Control Room) and monitored and stopped after a given period of time by the crew member. Panel lamps gave the crew member a "Ready" signal and indicated the time interval, 1, 5 or 15 seconds, at which time the clock was to be stopped. A duplicate clock in the Control Room, which started simultaneously with the Response Panel clock, was used to record the crew member's response to .01 of a second.

Prior to Flights I and II preflight (control) data was collected on the reaction time task so that comparisons could be made with the inflight data. The number of baseline trials were presented in Table 9, Chapter IV.

The number of sessions the task was performed, and the total number of trials for each crew member during each flight is presented in Table 34. The total number of trials for each flight were divided about equally among the 1, 5, and 15 sec. time intervals.

Table 34

Inflight Reaction Time Data Collected

Crew Member	No. Sessions Task Performed			Total No. Trials (all time inter.)		
	Flight I	Flight II	Flight III	Flight I	Flight II	Flight III
A	3	5	10	75	150	300
B	3	5	10	90	150	300
C	3	-	10	90	-	300

b. Time Estimation - This task required the crew member to estimate various intervals of time - 1 sec., 5 sec., 30 sec., and 1 min. After the lamps indicating the "Ready" signal and the length of time to be estimated had been noted, the crew member threw a switch on, and then off, when he judged that the time to be estimated had elapsed. The latter switch started and stopped a clock in the Control Room, from which the actual elapsed time was recorded to an accuracy of .01 of a second.

Preflight control data was also collected on this task and was presented in Table 9. Table 35 presents the inflight Time Estimation data collected. The total number of trials for each flight were about equally divided among the four time intervals to be estimated.

Table 35

Inflight Time Estimation Data Collected

Crew Member	No. Sessions Task Performed			Total No. Trials		
	Flight I	Flight II	Flight III	Flight I	Flight II	Flight III
A	3	5	10	40	74	172
B	3	6	10	32	88	144
C	3	-	9	44	—	142

The results obtained on the baseline and each of the three flights are presented in Tables 36A, B, C and 37A and B. Inspection of Tables 36A and 36B indicate no difference between baselines and Flight I and II data for reaction time. Further, chi square tests were performed on these data and indicated no statistically significant difference in pilot performance for baseline and flight data for Flights I and II. No baseline was collected on Pilots "A" and "B" prior to Flight III. However, 10 trials on each time interval for both reaction time and time estimation were given to Pilot "C" prior to Flight

Table 36 A

Comparison of Baseline & Flight I Data for Reaction Time Tasks
in Average Blocks of 5 Trials

Time Intervals	Pilot	Baseline Trials 5	10	15	20	25	30	35	40	Flight I Trials 5	10	15	20	25	30
1 Second	A	.99	.98	.99	.98	.98	.98	.98	.98	.99	.98	.97	.98	1.00	.98
	B	.99	1.02	1.01	.96	1.00	1.01	1.00	1.01	.99	.98	.98	.99	1.00	--
	C	1.01	1.00	1.01	1.04	1.02	1.00	1.02	1.03	1.00	1.02	1.01	1.00	1.00	1.00
5 Seconds	A	4.95	4.98	4.99	4.98	4.99	4.99	5.00	4.97	4.98	5.01	5.00	4.99	4.98	4.99
	B	5.01	5.00	5.02	5.03	5.00	5.01	5.01	5.01	5.01	5.00	5.01	5.01	5.01	--
	C	4.99	4.97	5.01	4.95	5.00	4.99	5.02	4.99	4.93	5.00	5.02	5.01	5.01	5.01
15 Seconds	A	14.99	15.00	15.01	14.98	15.00	14.99	15.00	15.00	14.97	14.98	14.98	15.00	14.98	14.98
	B	15.00	15.00	15.00	15.00	15.01	15.00	15.00	15.00	15.00	15.02	15.02	15.01	15.00	--
	C	15.00	15.01	14.99	14.99	15.03	15.00	14.99	15.00	15.00	15.00	15.00	15.01	14.98	14.99

Table 36 B

Comparison of Baseline & Flight II Data for Reaction Time

Tasks in Average Blocks of 5 Trials

Time Interval	Pilot	Baseline Trials		Flight II Trials									
		5	10	5	10	15	20	25	30	35	40	45	50
1 Second	A	.99	.98	.99	.98	.99	.97	.97	.97	.98	.99	.99	.99
	B	.99	1.00	.97	1.02	1.01	1.00	1.00	1.00	1.02	1.00	1.01	1.01
5 Seconds	A	4.99	4.99	4.99	4.99	4.98	4.99	4.98	5.00	4.97	5.00	4.97	5.01
	B	5.01	5.00	5.01	5.03	5.00	5.01	4.99	5.00	5.00	5.02	4.99	5.01
15 Seconds	A	14.99	14.98	14.99	15.01	14.98	14.98	14.97	15.00	14.98	14.97	14.99	14.99
	B	15.02	14.99	15.00	15.01	15.00	15.00	15.00	15.00	14.98	15.00	14.99	14.99

Table 36 C

Flight III Results on Reaction Time in Average Blocks of 5 Trials

Time Interval	Pilot	5	10	15	20	25	30	35	40	45	5(
1 sec	A	1.02	.98	.97	.98	1.00	.98	1.01	.99	.98	.
	B	1.01	1.00	.99	1.00	1.00	1.00	1.01	1.01	.99	1.
	C	1.01	1.02	1.02	1.02	1.01	1.02	.99	1.00	1.00	1.
5 sec	A	4.99	5.00	5.00	4.99	4.99	4.99	4.97	4.98	4.99	4.
	B	5.01	5.01	5.02	5.01	5.00	5.01	4.99	5.00	4.99	4.
	C	5.02	5.01	4.99	4.99	5.01	5.02	5.01	5.01	4.98	5.
15 sec	A	14.99	14.99	14.99	15.01	14.97	15.02	15.01	14.98	15.03	14.
	B	15.00	14.99	15.00	15.01	14.99	14.99	14.99	15.01	15.01	15.
	C	14.97	14.99	15.00	15.00	15.00	14.99	15.01	14.98	14.99	15.

	55	60	65	70	75	80	85	90	95	100
	1.01	.99	.97	.98	.99	1.00	.98	1.00	1.00	1.00
	1.01	1.01	1.01	1.00	1.02	1.00	1.01	1.01	1.00	1.02
	1.01	1.03	1.01	1.00	1.00	.99	1.00	1.01	1.00	1.00
	5.00	5.00	5.02	5.00	4.99	4.99	4.98	4.98	4.99	5.00
	5.00	5.01	5.02	5.01	4.99	5.02	5.00	5.00	5.00	5.01
	5.00	5.01	5.00	4.99	5.00	5.01	5.01	5.01	5.01	5.01
	14.98	14.98	14.98	14.99	15.00	14.99	15.00	14.98	14.97	14.99
	14.98	15.01	14.99	15.00	15.00	14.99	14.99	14.95	15.01	15.00
	14.98	15.00	14.98	15.03	14.99	15.01	15.01	15.00	15.01	14.99

III. Inspection of Table 36C indicates the reaction time scores obtained on crew performance for Flight III. Comparison of all previous collected baseline data on reaction time with Flight III data indicated no differences.

Chi square analyses of time estimation data performed on comparisons of baseline and Flight I and grouped baselines (Pre-flights I and II) and Flight II indicated no statistical significant differences between baseline and flight data. (Table 37A). Pooled baseline data when compared to Flight III data also indicated no significant difference. (Table 37B) However, Pilot "A's" time estimation for 1 second seemed under-estimated throughout Flight III rather than variable as in the baseline data and the Flight I and II data. However, this was not statistically significant.

The failure to find any significant results on the reaction time and time estimation tasks are in direct contradiction to data reported in the literature review in Appendix A (Refs. 20, 21, 22, 26 and 27). A number of explanations are possible for the high performance of the crew members in all three flights. First, the composition of the present crew influenced their performance. All crew members were very experienced test pilots whose performance and operation of actual flight vehicles were usually conducted on the basis of time (i.e., fuel and time to reach landing point). These individuals had a consistent, keen awareness of time which was not affected by the situation in the present study. Second, the lack of performance deficits on these tasks may be related to the ratio of non-mission related tasks to mission related tasks. In the studies reviewed, these types of tasks (time estimation and reaction time) were predominant. Loss of motivation and realization that these tasks meant nothing to the system or system operation could have produced the performance deficits noted. In the present study, these types of tasks were performed only 25-30 minutes during each 24 hour period. The crew accepted this as a reasonable task requirement and were highly motivated to perform well on these tasks.

The present study was not concerned with evaluating these tests as stress indicators. Therefore, no comments will be made as to its usefulness except that it did not indicate reaction to stress in the present study. Further, it is apparent that these tests have little operational validity since many means of time estimation are available

Table 37 A

Comparison of Baseline & Flight I & Baseline & Flight II Data for Time Estimation Tasks in Average Blocks of 5 Trials

Time Interval	Pilot	Baseline I					Flight I		Baseline II			Flight II		
		5	10	15	20	25	5	10	5	10	5	10	15	20
1 Second	A	.94	1.17	1.09	.80	--	1.24	1.18	.98	.99	1.08	1.11	1.13	--
	B	1.19	1.33	1.18	1.30	1.20	1.23	--	1.12	1.00	1.19	1.05	1.21	1.2[illegible]
	C	1.03	.92	.91	1.04	--	.93	1.01	--	--	--	--	--	--
5 Second	A	4.04	4.94	4.50	4.65	--	5.77	4.79	4.42	3.91	5.14	5.04	5.01	--
	B	4.72	5.61	5.20	4.83	4.71	5.30	--	4.90	5.03	6.20	5.13	4.77	4.[illegible]
	C	4.80	4.79	4.99	4.76	--	5.36	4.78	--	--	--	--	--	--
30 Seconds	A	25.99	26.79	27.13	29.79	--	31.97	29.40	25.89	27.09	30.08	29.69	30.37	--
	B	24.20	30.06	27.59	27.92	31.17	30.91	--	30.30	32.19	34.60	30.66	27.59	28.[illegible]
	C	23.74	23.79	26.89	29.64	--	29.28	28.49	--	--	--	--	--	--
60 Seconds	A	44.79	58.19	56.35	59.68	--	61.20	61.25	52.05	52.81	61.55	61.69	60.30	--
	B	51.90	60.02	60.67	56.09	50.11	57.21	--	58.57	66.02	68.76	62.73	57.[illegible]	5[illegible]
	C	[illegible]	[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]			--	--	--	

Table 37 B

Flight III Data for Time Estimation

Time Interval	Pilot	TRIALS 5	10	15	20	25	30	35	40
1 Second	A	.79	.81	.90	.83	.72	.67	.69	.69
	B	1.08	1.17	1.08	1.21	1.16	1.10	1.11	--
	C	.99	1.01	1.11	1.16	1.03	.94	1.01	--
5 Seconds	A	4.73	4.61	4.74	4.98	4.90	4.80	4.68	4.49
	B	4.44	5.15	4.99	5.40	5.80	5.81	6.41	--
	C	4.90	4.79	5.17	5.39	5.00	4.72	5.29	--
30 Seconds	A	27.12	28.51	29.32	29.49	30.12	29.01	29.08	28.64
	B	27.48	30.24	29.11	31134	33.11	30.93	31.24	--
	C	29.65	30.47	32.40	33.56	30.01	28.87	31.30	--
60 Seconds	A	55.65	56.84	59.80	58.11	60.46	59.70	56.69	56.64
	B	57.98	62.92	59.96	63.60	68.13	61.79	65.92	--
	C	59.22	60.86	66.27	67.76	60.56	56.25	65.62	--

in the spacecraft. Discrete reaction time tests such as the present are not related to the reaction times required for spacecraft procedures such as found in abort situations. In order to adequately simulate reaction-time performance, there must be operational and procedural validity as found only in dynamic control simulations.

2. Corticosteroid Analyses: The baseline samples collected have already been described. For Flights I and II, samples were taken for 49 hours prior to the onset of the flights. For Flight III, 72 hours of baseline data was collected. All samples were collected in individual containers and quick frozen. Every 24 hours during baseline collection and during the flights, the frozen containers were taken to Johns Hopkins Hospital where the analysis was performed All containers were labeled as to crew member, date, and time of day.

During Flight I, 46 samples were collected, furing Flight II, 48 samples were collected, and during Flight III, 122 samples were collected from each crew member. The results of Flight I and Flight II are presented in this report. The results of Flight III will not be presented since the number of samples collected were beyond analyses during the available time. A supplementary report will be submitted when the analysis is completed.

The volume of each collection for Flights I and II was measured carefully and the concentration of 17 hydroxycorticosteriods (17-OHCS) was determined by the method of Glenn & Nelson (Ref. 49). Fig. 64 presents the results of Flight I. The control period was 3 and 4 June, while the flight was 5 to 8 June.

Inspection of Fig. 64 indicates that during the control period, Pilot "A" showed a diurnal variation of his urinary 17-OHCS similar to that observed in other normal control subjects. He maintained a normal diurnal variation during the 3-1/2 experimental days. It is possible that the total excretion of urinary 17-OHCS might have been slightly higher during the third experimental day, however, it is not a significant increase.

Similarly, Pilot "B" had a normal diurnal variation during the control period, and he maintained his rhythm during the experimental period.

On the other hand, the results obtained on Pilot "C" are somewhat puzzling. During the control period the rate of excretion from 6 A.M. until 10 P.M. was approximately constant and then there was a decrease rate of excretion from 10 P.M. until 6 A.M. On June 5th and June 7th a maximal rate of excretion was obtained from 10 A.M. to 1 P.M. and from 1 P.M. until 6 P.M.

respectively. The observation of the results obtained on these two days would suggest a reversal of the diurnal variation. This pattern might be explained in the following fashion: Pilot "C" traveled from the West Coast after a period of time there. He arrived in Baltimore sometime on June 3rd. It is known that normal subjects maintain their diurnal variation in rhythm with the local time of the place where they stay for a period of time. When normal subjects are transported rapidly from one point of the globe to another they will adjust to the new conditions of time in two or three days. It is possible that the three hour difference between the West Coast and Baltimore might account for the fact that the control values of Pilot "C" did not show the clear cut variation expected for subjects living in the Eastern area of the U.S.A. During Flight I it happened by chance that the work cycle of Pilot "C" was exactly similar to that he would have had on the West Coast; in particular, his sleeping period corresponded to that he would have had on the West Coast. It is, therefore, possible that during the flight Pilot "C" had a variation which would have been that characteristic of a subject living on the West Coast.

On June 6th the values obtained on Pilot "C" were extremely elevated and completely out of range with the values prior and after that date. Because these results are somewhat surprising, efforts were made to study these urine specimens by the technique of paper chromatography and the isolation of the various hormones which are known to be included in the group of 17-OHCS. It was found that these hormones were not elevated and, therefore, the results reported for that day are an artifact. We know that certain drugs can produce such artifacts. Pilot "C" was taking pills for allergy as well as vitamin pills; however, Pilot "C" takes such pills regularly every day and particularly during the other days of the flight when no artifact was noted.

Similar to Flight I, there were two control days and three experimental days for Flight II. The results shown in Fig. 65 indicated that the two pilots ("A" and "B") maintained their normal diurnal variation during the three experimental days.

The results of Flight I and Flight II indicated there was no disruption of the diurnal variation of urinary 17-OHCS during the flight periods. This occurred even though the crew's sleep-work rhythm was markedly different from their normal rhythm as well as variable from day to day. The lack of disruption of the diurnal variation of 17-OHCS in Flight II is surprising since

the duty cycle was a 26 hour cycle. It is possible that the lack of shifts in their diurnal cycle was due to the short duration of both of these flights.

The literature review in Appendix A indicated there should be an elevation in 17-OHCS in anticipation of stress and after stress (Ref. 37), (Ref. 38), (Ref. 41). The lack of any general rise in 17-OHCS throughout either of the flights is an indication of the lack of stress due to confinement or sensory deprivation. Again the lack of any specific result due to stress may be laid to the composition of the crew. The use of trained well-motivated test pilot personnel appears to be indicated by these data. The results of the 7-day flight should substantiate the lack of any stress during these flights.

3. Blood Pressure: During each of the three flights the crews were required to perform blood pressure measures approximately every 8 hours. The purpose was to ascertain any effects of the situation on systolic pressure. Elevated systolic pressures are known to occur during intense excitement, anxiety, etc. Further, the lack of body movement within the simulator might also depress the blood pressures.

Tables 38A, 38B, and 38C indicate the systolic blood pressure levels during each of the three flights. Inspection of the tables indicates little change in blood pressure except in one instance. This occurred in Pilot "B" prior to re-entry and is attributed to general excitement. In Flights I and II insufficient data was collected since during the dynamic phases no other pressures were taken. In Flight III, sufficient data is available for analysis. Table 39 presents the averaged systolic blood pressures for all three pilots compared to mission tasks. There is no indication of significant variation of blood pressure as compared to mission tasks. Table 40 presents the relationship of systolic blood pressure to diurnal variation. Inspection of this table indicates no diurnal trend in the averaged blood pressure readings.

The results of the inflight blood pressure measurements did not yield any indication of stress. Whether this measure is sufficiently sensitive to indicate the occurrence of stress remains in doubt. Further, the method of taking the blood pressures were extremely crude and certainly affected the results. No general excitement was noted by systolic pressures during any of the various mission phases or crew tasks. (There was one exception which was noted above). In general, we may conclude that the crew showed no general excitement or anxiety

Table 38 A

Systolic Blood Pressures During Flight I

Date	Mission Time	EDT	Pilot	Systolic Pressure
5 June	-2.0	0830	A	105
	Pre-Flight		B	120
			C	108
5 June	5.5	1600	A	118
			B	136
			C	126
6 June	21.0	0730	A	110
			B	135
			C	115
6 June	24.0	1030	A	112
			B	138
			C	108
6 June	32.5	1900	B	123
			C	110
6 June	34.0	2030	A	112
7 June	40.0	0230	A	116
			C	105
7 June	41.5	0400	B	122
7 June	50.0	1230	B	132
	50.0	1230	C	110
9 June	77.0	1630	A	120
	Post-Flight		B	130
			C	108

Table 38 B

Systolic Blood Pressure During Flight II

Date	Mission Time	EDT	Pilot	Systolic Pressure
19 June	-2.5	0800	A	110
	Pre-Flight		B	124
19 June	8.00	1830	A	110
			B	135
20 June	17.00	0330	A	115
			B	135
20 June	24.00	1030	A	105
			B	135
20 June	32.0	1830	A	108
			B	125
21 June	40.0	0230	A	110
			B	125

Table 38 C

Systolic Blood Pressure During Flight III

Date	Mission Time	EDT	Pilot	Systolic Pressure
6 July	-2.0	0830	A	105
	Pre-		B	134
	flight		C	110
6 July	5.0	1530	A	104
			B	128
			C	108
6 July	12.0	2230	A	108
			C	108
7 July	16.0	0230	B	126
7 July	20.5	0700	A	112
			B	110
7 July	24.0	1030	C	118
7 July	30.0	1630	B	130
7 July	33.0	1930	C	104
7 July	34	2030	A	122
7 July	36	2230	A	108
			B	118
8 July	40	0230	C	102
8 July	43	0530	B	126
8 July	48	1030	A	102
			B	116
8 July	52	1430	B	108
8 July	52	1430	C	112
8 July	55	1730	A	102
			C	112
8 July	56	1830	B	114
9 July	64	0230	A	118
			B	120
9 July	66	0430	C	94
9 July	76	1430	A	110
			B	126
			C	108
9 July	82	2030	A	112
			C	103
9 July	84	2230	B	125
10 July	89	0330	A	105
			C	98
10 July	92	0630	B	120
10 July	97	1130	A	110
			B	112
10 July	99	1330	B	122
10 July	105	1930	A	108
			C	105
10 July	107	2130	B	122

Table 38 C (Cont'd)

Systolic Blood Pressure During Flight III

Date	Mission Time	EDT	Pilot	Systolic Pressure
11 July	113	0330	A	100
			C	103
11 July	115	0530	B	118
11 July	122	1230	A	120
			B	115
11 July	123	1330	C	115
11 July	131	2130	A	98
			B	132
			C	92
12 July	139	0530	A	102
			C	112
12 July	146	1230	C	107
12 July	148	1430	A	115
			B	118
12 July	155	2130	C	108
12 July	156	2230	B	128
13 July	163	0530	A	110
			B	162
			C	108
13 July	165.5	0800	A	110
	Post-Flight		B	135
			C	110

Table 39

Averaged Systolic Blood Pressures & Mission Tasks

Mission Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Crew Tasks	C	C	N	N	C	N	M	N	M	M	M	M	M	M	M	N	C	M	M	M	M	M	M	N	M	M
Average Systolic Pressure	113												114											113		
Mission Time	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	
Crew Tasks	M	M	M	M	M	M	M	M	M	N	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	
Average Systolic Pressure	119									109										115						
Mission Time	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	
Crew Tasks	M	M	M	M	N	M	M	M	N	C	M	M	M	M	M	M	M	M	M	M	C	C	C	C	C	
Average Systolic Pressure	110												111													
Mission Time	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	99	99	100	101	102	103
Crew Tasks	C	M	M	M	M	M	M	M	C	C	C	C	C	C	C	C	M	M	M	M	M	M	M	M	M	M	N	C
Average Systolic Pressure	115								114							108								115				
Mission Time	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125				
Crew Tasks	N	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	N	C	M	M	M	M				
Average Systolic Pressure	112									107								117								
Mission Time	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147				
Crew Tasks	M	M	N	M	M	M	M	M	N	M	M	M	M	M	N	C	M	M	M	M	M	M				
Average Systolic Pressure	107															107										
Mission Time	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164									
Crew Tasks	M	M	M	M	M	M	M	M	M	M	M	M	C	C	C	C	C									
Average Systolic Pressure	119												124													

C - Control Task
M - Monitoring Task
N - Navigation Task

Table 40

Averaged Systolic Blood Pressure Compared

to Diurnal Variation

Date	EDT	Average Pressure for Three Pilots	Date	EDT	Average Pressure for Three Pilots
6 July	0600-1200 1200-1800 1800-2400	116 (Pre-Flight) 113 108	13 July	0000-0600 0600-1200	127● 118 (Post Flight)
7 July	0000-0600 0600-1200 1200-1800 1800-2400	126 * 113 130 * 113			
8 July	0000-0600 0600-1200 1200-1800 1800-2400	114 109 109 114 *			
9 July	0000-0600 0600-1200 1200-1800 1800-2400	111 - 115 113			
10 July	0000-0600 0600-1200 1200-1800 1800-2400	102 114 122 * 112			
11 July	0000-0600 0600-1200 1200-1800 1800-2400	107 - 117 107			
12 July	0000-0600 0600-1200 1200-1800 1800-2400	107 - 113 118			

* - Single Reading

● - One highly elevated reading

throughout the 7 day, Flight III, mission as measured by the systolic blood pressures.

4. Crew Diets: As stated earlier in this report, two different caloric levels were used during the flights. For Flights I and II, 1800 calories were used and for Flight III, 1500 calories were utilized. The food in all three cases was tasty and well prepared. A fresh supply of food was placed into the main simulator every 24 hours and was wrapped in individual meal containers. The hot portions of the food had to be heated in the simulator oven. This process took approximately 30 minutes. Appendix F presents the diets for each of the three flights.

In general, the crew's comments concerning the food was that it was well prepared and enjoyable. However, they indicated that it appeared too plush and under operational conditions more austere food rations would probably be provided. However, studies performed on stress conditions have indicated the importance of well-prepared and variable food diets. The crew's responses concerning the plush food probably again indicates their general lack of reaction to any stress inherent in the present study.

Body weights indicated an average loss of 1-1/2 pounds per man in Flights I and II. During Flight III, Pilot "A" lost 7-1/2 pounds, Pilot "B" lost 9 pounds, and Pilot "C" lost 6-1/2 pounds. A previous study indicated the acceptability of the 1800 calorie diet which was confirmed in Flights I and II (Ref. 27). It does appear that the 1500 caloric diet was too stringent. The weight losses in all three pilots were consistent and striking. Though in the present study there was no method to evaluate what the weight losses represent in terms of body nitrogen, body water, etc., these would be of considerable interest. Future studies should be conducted to evaluate these metabolic considerations. This would be of considerable importance during prolonged flights in a weightless condition.

5. Physical Conditioning: Crew physical conditioning was evaluated prior to each flight and within 3 hours after the flight termination. Comparison of crew status after each flight was made with the pre-flight data. Tables 41A and 41B and Tables 42A and 42B present the performance of the crew before and after Flights I and II. Inspection of these tables indicate no detectable loss of physical

TABLE 41 A

Physical Endurance Evaluation

Baseline for Flight I

	JUMPING JACKS	JUMP ROPE BOTH FEET	JUMP ROPE ONE FOOT	JUMP ROPE STEPPING	PUSH UP	SIT UP	CHIN	WEIGHTS		
								50 lb Press	50 lb Back Curl	50 lb Swing Ball
Pilot A	No.-101 Time-92 sec.	No.-101 Time-45 sec.	No.-97 Time-42 sec.	No.-81 Time-42 sec.	No.-30 Time-40 sec.	No.-40 Time-93 sec.	No.-10% Time-27 sec.	No.-19 Time103 sec.	No.-20 Time-55 sec.	No.-20 Time-65 sec.
Pilot B	No.-101 Time103 sec.	No.-81 Time-45 sec.	No.-86 Time-45 sec.	No.-60 Time-40 sec.	No.-34 Time-45 sec.	No.-50 Time130 sec.	No.-6 % Time-21 sec.	No.-27 Time105 sec.	No.-15 Time-62 sec.	No.-34 Time-62 sec.
Pilot C	No.-101 Time-89 sec.	No.-59 Time-43 sec.	No.-37 Time-33 sec.	No.-52 Time-40 sec.	No.-28 Time-40 sec.	No.-30 Time-90 sec.	No.-6 Time-14 sec.	No.-16 Time-80 sec.	No.-14 Time-30 sec.	No.-41 Time-55 sec.

Table 41 B

Physical Endurance Evaluation

Foot Flight I

	Jumping Jacks	Jump Rope Both Feet	Jump Rope One Foot	Jump Rope Stepping	Push Up
Pilot A	No. -101 Time-92 sec	No. -101 Time-45 sec	No. -97 Time-40 sec	No.-100 Time-[illegible] sec	No. -30 Time-42
Pilot B	No. -101 Time-92 sec	No. -85 Time-48 sec	No. -85 Time-45 sec	No. -90 Time-67 sec	No. -34 Time-42 se
Pilot C	No. -101 Time-87 sec	No. -59 Time-65 sec	No. -33 Time-37 sec	No. 60 Time-51 sec	No. -30 Time-45 se

Table 42 A

Physical Endurance Evaluation

Baseline for Flight II

	Jumping Jacks	Jump Rope Both Feet	Jump Rope One Foot	Push-Up	Sit-Up	Weights	
						50 lb Press	50 lb Curl
Pilot A	No. -101 Time-81 sec Rate-1.25	No. -100 Time-62 sec Rate-1.61	No. -100 Time 46 sec Rate-2.17	No. -28 Time-41 sec Rate-.683	No. -40 Time-93 sec Rate-.432	No. -15 Time-67 sec Rate-.224	No. -20 Time-45 sec Rate-.444
Pilot B	No. -101 Time-102 sec Rate-.990	No. -80 Time-58 sec Rate-1.38	No. -60 Time-34 sec Rate-1.76	No. -35 Time-45 sec Rate-.756	No. -50 Time-145 sec Rate-.345	No. -15 Time-107 sec Rate-.140	No. -15 Time-65 sec Rate-.231

Table 42 B

Physical Endurance Evaluation

Post Flight II

	Jumping Jacks	Jump Rope Both Feet	Jump Rope One Foot	Push-Up	Sit-Up	Weights	
						50 lb Press	50 lb Curl
Pilot A	No. -101 Time-92 sec Rate-1.09	No. -100 Time-34 sec Rate-2.56	No. -100 Time-44 sec Rate-2.27	No. -30 Time-40 sec Rate-.750	No. -40 Time-91 sec Rate-.439	No. -15 Time-65 sec Rate-.231	No. -20 Time-42 sec Rate-.476
Pilot B	No. -101 Time-98 sec Rate-1.03	No. -80 Time-47 sec Rate-1.70	No. -60 Time-29 sec Rate-2.07	No. -35 Time-41 sec Rate-.854	No. -50 Time-132 sec Rate-.379	No. -15 Time-86 sec Rate-.174	No. -15 Time-35 sec Rate-.428

conditioning which can be related to spatial confinement. In fact, the recommended U.S. Navy Self-Conditioning program which has some exercises comparable indicate that with the push-up and sit-up exercises, the crew members in the present program would be classified as excellent in both the pre- and post-evaluation sessions. This U.S. Navy program is shown in Table 43.

On Flight III the physical endurance evaluation program was the performance of the Harvard Step Test. The results are presented in Table 44. This table clearly indicates that crew physical conditioning did not deteriorate after the 7 day flight. This table presents the number of steps made by each crew member during a 5 minute period. The task was to step up and down a 19-1/2 inch-high box in coordination with a metronome. The crew member must perform 150 steps in 5 minutes. Further, another measure is introduced which considers pulse rate taken by precordial ausculation at 3 time intervals at the end of the test. The deviation of the score is explained in Appendix C. This is also presented in Table 44. All scores indicate an above average state of physical fitness. At the end of the Flight III Step Test for each crew member, it was noted that all crew members had excellent rhythm and performed the test without difficulty. At the end of Flight III, some stiffness in the legs was noted but this disappeared rapidly and apparently did not affect crew performance on the Step Test.

The inflight exercise program which was described in a previous chapter was carried on during all three flights using the stretch-type exerciser. Except for the breakdown of the exerciser in Flight III, for 8 hours, the exerciser was used continuously. During this breakdown a substitute exercise program was given to the crew and is presented in Appendix C. During Flight I the crew was instructed to perform the exercise program at their option, during Flight II the crew was instructed to perform the exercise program for 5 minutes during every off-duty period, and during Flight III the crew was instructed to perform the exercise program for 8 minutes every other off-duty period. Also during Flight II the crew suggested that the exercise be conducted every other off-duty period. With the concurrence from the control room, this procedure was followed during the second half of Flight II.

Table 43

Recommended Levels U. S. Navy Self-Conditioning Program for Persons Under 40 Years of Age.

Exercise	Performance Time	Unsatisfactory	Satisfactory	Good	Excellent	Out-Standing
Sit Ups	60 sec.	0-19	20-24	25-29	30-35	36 & above
Push Ups	60 sec.	1-14	15-16	17-19	20-24	25 & above

Table 44

Physical Endurance Evaluation for Flight III

	Initial Examination		Pre-Flight III		Post-Flight III	
	Trips	Score	Trips	Score	Trips	Score
Pilot A	155	57	152	64	151	58
Pilot B	151	64	150	61	155	60
Pilot C	154	61	152	56	151	54

Crew comments concerning the inflight exercise program indicated the usefulness of this portion of the study. The crew indicated that, "You need the exercise most when you think you don't require it." Further, in the present study there was no general weakness as noted in a previous study (Ref. 27). There was also no back or cervical pain which could be associated with the reduced spatial volumes. There was also no indication of extraneous motor movements as described in the literature review and termed "stimulus hunger." (Ref. 5). While the crew did not generally appear to be affected by the stress of the present environment, the utility of the exercise program cannot be overemphasized. It is a distinct possibility that poorly conditioned crew members, who through the course of the flights would have developed back pains, leg weakness, etc., might have shown performance decrements. These performance decrements would have had somatic overtones which could have affected performance. It was decidedly this situation which the physical conditioning program was concerned with.

Another emphasis of the present physical conditioning program was to develop and maintain endurance rather than strength. This appeared to be required due to operational emergency landings. Further, once endurance was obtained, what was the best method of maintaining this level? It appears from the present study and the crew level prior to the onset of the program, that 6 weeks of preconditioning was adequate. Further, the results obtained from each of the flights, particularly the 7-day Flight III, indicates that physical endurance was maintained by the inflight exercise program. This result is particularly significant since it is well known that deconditioning occurs rapidly after any period of general lowered inactivity for 3 days or longer. This result was quite obvious in a previous simulator study conducted at the Martin Company in 1961 (Ref. 27).

Though the present study did not attempt to simulate the exercises to be utilized in a weightless situation, the present study does have implications to operational space flight situations. It is a reasonable assumption that long term weightlessness exposure could produce deconditioning similar to, or in excess to, that experienced in reduced spatial environments. Therefore, some exercise regime must be

provided to avoid rapid deconditioning. The program utilized in the present study was simple, used a stretch-type exerciser as the only apparatus, was performed only an hour a day, and maintained the physical endurance of the crew. It, therefore, seems applicable to long term space flight situations.

Another type of exercise program should be examined more carefully in future studies. These are the so-called isometric exercises in which the muscles operate against an immovable resistance. These exercises require no apparatus and are only to be performed for 15 minutes a day. Though these exercises tend to develop musculature at a rapid rate, little data is available as to their utility in maintaining endurance. The lack of exercise apparatus combined with the short time of exercise make these types of exercises attractive.

In conclusion, it is believed that the physical conditioning and inflight exercise program achieved the goals of conditioning the crew and maintaining the endurance obtained throughout all flights. Further, the exercises appeared to aid the crew in reducing any tension or somatic complaints due to the spatial confinement within the simulator.

F. Medical & Psychological Evaluation

The results of the medical and psychological studies are essentially negative as to direct results from sensory deprivation and confinement in the three flights. With the exception of the severe weight loss noted in all three crew members after Flight III (due to the low caloric input), there were no medical or physiological indications which could be attributed to stress. The fatigue exhibited by the crew after Flight I was related to the duty cycle. After the change of the duty cycle for Flights II and III, there were no apparent signs of fatigue even after 7 days.

The results of psychological evaluation of the crew after each flight indicated no gross difficulties. As stated earlier, the Rorschach Projective Test and the Wechsler Adult Intelligence Scale were administered early in the program. Only the Rorschach Test was administered after Flights I and III. The results of the Rorschach Test after Flight I indicated no generalized personality deterioration. There was a general decrease in reaction time in all three crew members. There also appeared to be somewhat of a loss in creativity and an increase in irritability. These findings for the 75 hour, Flight I, clearly indicate that the crew members in the present study can be counted on to perform adequately for long periods of time without major personality deterioration.

The results of Flight III indicated that all crew members demonstrated no personality disturbance. In terms of comparison with the Flight I results, all crew members showed improvement despite the 7 day period of Flight III. All crew members showed minimal personality fluctuation from baseline data. There were some signs of irritability and reduced reaction time. However, these were all minimal.

The examining psychologist concluded after the evaluation of the data was completed, the following:

1. Length of flight (up to 7 days) does not appear to be a factor in precipitating disturbance in the personality or social spheres with the crew members who participated in each of the flights.

2. The most important adjustment appears to be familiarity with operational procedures. The greater the training and preparation the less the chance of difficulties.

The psychiatric interviews conducted after Flight I and Flight III did not uncover any gross emotional problems which could be attributed to any of the flights.

In general, the results of the medical and psychological evaluation indicate no effects which can be attributed to sensory deprivation and confinement in the present study. The effects noted on the Rorschach in Flight I may be attributed to the duty cycle rather than confinement stress. Since in Flight III, with a change in duty cycle, the effects on the Rorschach were quite minimal even though the flight was twice as long. Observation of the crew throughout all three flights and preliminary analysis of tape recorded data have indicated no occurrence of bizarre behavior, intense hostility, gross desocialization, or personality disturbances. On the contrary, the crews constantly seemed well motivated, responded well to all control room requests, and appeared friendly to each other.

It should also be noted that mild irritability can be expected with long wakefulness periods. In fact, one may argue that this would be an adequate adjustment to fatigue if it did not interfere with performance. This, in fact, was the case during the present flights. Again the main variables which appear to explain the lack of effects due to the duration of the flights are the crew composition and training.

G. Simulator Displays and Arrangement

During the course of the study, a number of recommendations were made by the crew as to the adequacy or inadequacy of the crew displays, crew controls, and the general internal arrangement of the simulators. These will be reported in this section with some possible implications to operational systems.

1. All crew members agree that the scan pattern in both simulators made proper control difficult. Due to this poor scan pattern, crew workload was extremely high and did not free enough crew capability for possible emergency situations. Redesign of the display panel with the provision of a digital readout for velocity corrections, the inclusion of the 3 attitude rates inside or near the 3-axis ball, and a rate of climb readout should improve pilot workload. The redistribution of these displays and their proper placement should improve the scan pattern for all phases.

2. The abort light should be prominently placed near the 3-axis ball so as to be visible during flight control phases as well as during the monitoring phases.

3. The excursion vehicle lunar landing displays were highly unsatisfactory for flight control. The primary information requirements for lunar landing in terms of displays are as follows: $\dot{h}$, altitude, range rate ($\dot{X}$ & $\dot{Y}$), attitude, and attitude rates. These display requirements do not consider a predictive lunar landing guidance scheme. Further, within the excursion vehicle, additional information displays related to onboard systems are required. These displays apply only to a one man excursion vehicle as investigated in the present study.

4. The complete duplication of flight control displays for the navigator's position within the main vehicle.

5. The malfunction warning indicators should be placed directly on the panel instead of above the panel.

6. The throttle box in the main simulator should be placed forward of its present position or directly on the display panel so as not to break the pilot scan pattern. This also includes the abort button handle.

7. During any non-dynamic phase, the malfunction lights should be out rather than green (an indication of a "go" condition). The amber and red lights should be active to indicate a marginal condition or a malfunction it it occurs. A manual stick switch should be installed, so that upon activation system status could be determined and immediately turned off, if the pilot so desires.

8. A radio call light has been suggested as a requirement. Further, this light should have a prominent place on the panel.

9. A switch on the stabilization and control panel has been suggested so as to allow the navigator to fly one axis in order to aid the commander.

10. The communication panel should be redesigned according to conventional aircraft design.

11. An improved design in control stick is required with the possible consideration of a 3-axis stick instead of a 2-axis stick and yaw pedals.

12. Provide a capability to the crew for securing any audio-warning signal after it has been noticed.

13. Provide audio phone jacks in the sleeping area.

14. Improve toilet and washing facilities.

15. Improve sound attenuation for the sleeping area to eliminate or reduce noise from auxillary power sources.

16. The center seat is excellent for monitoring the display panel during the coast periods.

There were other comments by the crew concerning displays, controls, general arrangement. However, these appear to be peculiar to the present simulation and have no operational significance. The above comments should provide some general design information for long term spacecraft operation.

VI. Concluding Remarks

The results obtained from the three flights which were reported in the body of the report have been discussed in detail. Based upon these results and on the general design of the study a number of conclusions can be made. First, it is apparent from all crew performance evaluation and other associated measures of crew status that there was no indication of stress due to confinement and sensory deprivation. Second, the lack of practice between the last training session and the time of flight task performance appears to influence the level of performance obtained. Third, lunar landing as simulated in the present study can be performed well either with a large main vehicle or with a smaller excursion vehicle. Fourth, the importance of adequate display-control compatibility for high crew performance cannot be overemphasized. In fact, the key to the maintenance of high crew performance might be contained with the display-control system. Fifth, the inflight exercise program developed achieved its purpose in maintaining crew endurance. Last, the importance of realistic simulation in determining crew performance levels, work load, and tasks also cannot be overemphasized in its implication to space flight system design.

A. Sensory Deprivation and Confinement

The lack of specific effects due to sensory deprivation and confinement are somewhat surprising when consideration is given to the vast number of studies reported in the literature. One may question the reasons for the results obtained in the present studies as compared to the studies in the literature. Was there actually stress in the present simulation? How realistic was the present simulation in producing stress? What variables influenced or modified the stress that was inherent in the present situation?

The question as to the presence or absence of stress in the present situation appears to be a matter of definition. It is somewhat intuitive that unless some measured variance in either physiological, psychological, or task performance appears in the so-called stress situation as opposed to non-stress situations, that stress is not present for the crew. The large individual differences in reaction to situations and the different modes which stressed behavior can take also demand the above empirical approach. For example, under the same set of environmental conditions certain individuals might exhibit performance decrements while others might increase their level of performance as compared to pre-"stress" conditions. This effect is most noticeable with anxiety stress. Certain individuals respond to anxiety as if it were a positive motivating force, thereby increasing performance. Others respond in a negative manner and exhibit performance decrements. Based upon crew performance and general behavior within the present study, the situation must be considered as non-stressful. The crew composition then becomes an obvious important variable in reaction to stress.

Was the present situation of sufficient reality to produce any stress which might exist in the actual flight situation? This, of course, is most difficult to evaluate. In the present study as in the actual expected flight situation, no attempt was made to provide a completely reduced sensory environment or complete confinement. However, care was taken to reproduce an environment which was close to the expected actual environment. The crew had a communication link with the control room, auxillary power unit noise was contained within the vehicle (i.e., air conditioner noise), conversation within the simulator was not limited, and a music system was provided to relieve any boredom which might occur. Other known environmental factors, however, were not simulated in the present study. Whether these would contribute to sensory deprivation or confinement stress is unlikely, but is only conjectural with currently available data.

It may be concluded from the present study that no effects of sensory deprivation were evident in the crew members. All performance tasks, from the complex control tasks to the behavioral response tasks, were negative in stress effects. Further, all inflight psychophysiological measures indicated no reaction to stress. The question as to the presence or absence of stress in the present flights, or in an operational lunar system, must also be considered empirically. The lack of reaction by the crew has indicated the situation to be stress free. Further, in actual flight, it is believed that higher levels of motivation will be obtainable than apparent in the present study. Therefore, little performance effects should be noted due to confinement or sensory deprivation. The lunar spacecraft or any long term space flight system does have a sensory environment which is different from daily life but is not a sensory deprived environment. The spatial volumes of the spacecraft are small, but apparently not sufficiently small to affect crew performance.

The results obtained in the present study may best be explained in terms of crew composition, crew training and experimental design. The well experienced personnel utilized in the present study contrast with the subjects utilized in the studies reported in the literature review. It is apparent that the experience and pilot skills of the present crew was quite high as compared to other studies reported. Further, and possibly more important, was the level of motivation exhibited by the crew in the present study. All crew members were professional aviators who are intensely interested in space flight problems. Further, they considered the simulator environment as non-threatening and each of the flights were considered as part of their professional task(i.e., another test flight). As stated earlier, the crew was quite knowledgeable about all flight events except aborts and malfunctions. There was no uncertainty about the flights, and the crews' primary concern was to learn the flight control tasks during the specified training time.

The training periods, themselves, were designed to provide a high level of skill prior to the flights. A lesser training period might have

caused some difficulty in subsequent flight performance. However, highly skilled and experienced personnel seldom demonstrate performance decrements even under the most trying conditions.

Though the present study was not specifically designed to evaluate the type of personnel who should be selected for long term space flight, the results bear upon selection criteria. Consideration of only one of the factors involved in space flight, sensory deprivation and confinement, indicate that technical or physiological qualifications are not sufficient to insure adequate or high performance under this stress. Lack of reactivity to the present situation by the crew may best be explained by the relationship of the present situation to other situations in their flight experience. Placed in this perspective, the present confinement or sensory deprived situation appears nothing more than another test flight except for the longer duration. This experience is the most difficult aspect of the crew personality to train. In fact, it is probable that no simulated training can be equated to actual flight experience which the crew members in the present study had in abundance. These above statements should not be misconstrued to indicate that only highly skilled test pilot personnel are capable of long term space flights. However, when attempting to select from a sufficiently large population, the test pilot group appears ideal. Not only is their experience appropriate but the performance skills required in space flight, particularly in lunar landing, are similar to present high performance aircraft skills.

A number of factors in the present study probably aided the crew in maintaining high performance. However, even without the appropriateness of these factors, it is believed that crew performance would not have shown dangerous decrements. The following factors merely aided the crew in performing their skills by attempting to eliminate fatigue factors and provide a general feeling well-being. Three factors were initially considered as falling into the above category: diet, duty cycle, and in-flight exercise. The crew comments on the diet was that it appeared sufficient and the food was tasty, however, all crew members concurred that in an operational situation, the diet would probaly be more austere and for periods of 7 to 14 days or even longer would not cause any difficulty. Whether a less acceptable diet would have had the same effect on the pilot population is not known. However, these results do contrast to other studies in the literature where diet acceptability appeared to have a major influence on crew performance. The apparent lack of concern about the diet in the present study may be traced to the acceptable diet used and crew composition.

The effect of the duty cycle on performance was not directly demonstratable, as indicated in the body of the report. However, the crew reports and their general appearance indicated that the 26-hour duty cycle was superior to the 24-hour cycle. This cycle (26-hour) was also more amenable to the demands of the trajectory and crew tasks for the lunar mission.

The preconditioning and inflight exercise programs utilized in the present study eliminated pain and other somatic complaints common in confinement in reduced spatial environments (Refs. 5 and 27). The data indicated that the preconditioning program was of sufficient length to combat any effects of the reduced spatial volume on physical conditioning. The inflight exercise program should, from the present data, be performed every other duty period for 8 to 10 minutes. This regime not only maintained endurance but also did not develop into a boring chore for the crew. The inflight exercise program, used in the present study, may have an application to operational space flight missions because it has only one simple exercise apparatus and takes only a total of one hour each day

B. Lack of Practice

One of the results of the present study which deserves further comment is the effect of lack of practice on crew task performance. It was apparent in the present study with the many different types of procedures, tasks, and displays that some loss in performance occurred in specific procedures associated with flight control tasks. Though the pilots were generally able to perform the flight control tasks adequately, proper sequencing of engines and control settings in some cases caused difficulty. This result is not unexpected since highly skilled, complex tasks often show decrements after relatively short periods of time, particularly when other activities intervene between the last practice session and the actual flight task. This occurrence was evident not only in some of the flight tasks, but also in periods between flights prior to the onset of baseline data collection. Further, the present program did not stress training and practice on putting together the entire mission tasks and procedures prior to each flight. The effect of this lack of training must also be considered.

Three obvious solutions are available to combat the effects of lack of practice. One solution is quite basic and would have occurred in the present study had time permitted. This is the over-learning and practice of all tasks in their proper mission sequence to insure that the highest learning plateau had been reached prior to the flight. The number of trials required to achieve a firm learning plateau must be empirically determined for each task.

The second solution and one which has previously been suggested by others is to divide the workload of each crew member so as to make each of the individual crew tasks simple. The simpler task plus the elimination of some procedures, and the redistribution of task responsibility should also aid the crew member in maintaining his proficiency.

The third solution involves a technique that would provide a means of maintaining proficiency on extended space flights by practicing the tasks before the actual time. Use of an onboard computer to practice the various control tasks and procedures would provide a reasonable means of practicing these tasks. This could most reasonably

be performed during the midcourse coast periods.

It appears, also, that more research is required to precisely evaluate the effects of lack of practice on task proficiency, particularly of lunar landing tasks. Though any of the solutions given above appear reasonable, they are dependent upon the precise amount of deterioration in performance during various periods of non-practice. A strictly designed experiment should yield data useful for both system and mission design criteria for crew tasks and training.

C. Comparison of Main Vehicle and Excursion Vehicle Landings

One of the goals of the present study was to compare crew performance during a main vehicle landing as opposed to an excursion vehicle landing. In general, the results indicate that crew performance in both modes of lunar landing were performed quite well. However, the difference in performance between the two modes of lunar landing as simulated in the present study should be explained. The primary difference between the two simulators which contributed to performance differences and task difficulty was the lack of display system optimization within the excursion vehicle.

Earlier concepts of lunar landing had primarily considered the main vehicle mode of lunar landing as the one to be used. Therefore, a great deal of effort had been expended in the development of a display system within the main vehicle which could not only meet the lunar landing requirements but also re-entry, midcourse and other mission phases. Within the present study, the main vehicle simulator including the display system, were completed prior to the onset of the study. In contrast, the excursion vehicle display panel was designed within the confines of the present study with the inherent time difficulties. In the main vehicle simulator three major and two minor revisions of the display panel occurred prior to the one used in the present study. This was not possible with the excursion vehicle display system due to time and financial limitations.

Though some display system optimization within the excursion vehicle could have occurred, part of the experimental design of the present study called for a stern test of the excursion vehicle concept. Further, in order to evaluate any effects of sensory deprivation and confinement the excursion vehicle design and display system provided an arduous task. Therefore, no attempt was made to provide any optimization of the excursion vehicle display system.

The lack of a proper display system within the excursion vehicle provided tasks during lunar landing which was most difficult and had a high pilot workload. Further, the excursion vehicle used contained only one-man as opposed to current requirements which have a two-man excursion vehicle. The second man within the excursion vehicle would not only reduce the workload but would also provide a second source of information to the pilot during the landings.

Therefore, any differences in crew performance between the main and excursion vehicle landings within the present study appear due to the lack of optimization of the excursion vehicle display system. Further, the lack of gross performance deficits with the excursion vehicle tasks is again an indication of the lack of reactivity of the crew to the stress of confinement or sensory deprivation despite display system difficulties.

D. Display-Control System Effects on Performance

The above section has already indicated the importance of the display-control system on crew performance. In fact, with the composition of the crew in the present study, continued high performance appeared to be determined by the display-control system rather than any stress of the situation. Though the adequate provision of proper information to pilots has been a consideration for many years, its importance was clearly demonstrated in the present study. No other major factor appears to have as much influence on the lunar landing maneuver or on any other flight phase than the display-control system.

The display-control systems in both vehicles used in the present study were far from optimum as evidenced by the crews' comments. Considerable effort should, therefore, be expended to develop these displays since their importance on crew performance cannot be overemphasized.

E. Realistic Simulation

One of the major results of the present study which was stated earlier was the lack of reactivity of the crew to the stress of the present situation. An important variable which was already mentioned was crew composition. However, equally important in the present simulation was the realism of crew tasks, the internal configuration, and each flight. Without a doubt, this realism contributed greatly to the results obtained. One might conjecture as to the outcome of other studies in the area of sensory deprivation and confinement if the tasks were more realistic, and if there was task feedback.

The present simulation, because of the realism, also provided the crew with excellent training for initial familiarization with the lunar mission as well as research data. Though this realism existed, the engineering data obtained from the present study should not be used as design data.

Continued research with the present type of simulation with increased sophistication should provide design data in the area of display and control dynamics directly applicable to lunar or other long term space flight missions.

VII. Appendices

Appendix A

Literature Review

A. Clinical and Anectodal Studies

The studies in this area have recently been reviewed and discussed by a number of authors (Ref. 5), (Ref. 6). The data is fairly diverse and generally unsystematized. The effects of monotony, changes in many aspects of behavior, hallucinatory experiences, plus a desire for human contact are found in reports by Byrd (Ref. 7), Burney (Ref. 8), Ritter (Ref. 9), and others. A specific clinical report on aviators by Bennett (Ref. 10) indicating phenomena quite similar to those reported in isolation and confinement situations is of particular interest to this review. The occurrence of feelings of isolation, unreality and dream-like states appear to occur in a "third of jet pilots" who fly in high performance aircraft. This phenomenon has been termed the "breakoff phenomenon."

Anectodal data also exists in medical situations, i.e., confinement of patients in polio respirators (Ref. 11), (Ref. 12). These data indicate changes in behavior akin to those found in confinement and sensory deprived situations. In general the data found in the anectodal and clinical literature cannot be utilized to generalize to the space situation. The reports of explorers, prisoners, etc. are usually individual experiences and very introspective in nature. Further, the stress and the confinement situation itself, upon which these experiences are based appear to be more severe than that contemplated for long term space flight except for a dire emergency. The data reported by Bennett (Ref. 10) on jet pilots is extremely important if valid. Its validity is somewhat in doubt primarily because of the size of the sample interviewed. Again, an attempt to utilize data from medical situations is difficult. This is primarily due to lack of knowledge as to specific mental dysfunction exhibited by any illness as opposed to the confinement situation itself.

The above statements should not be misconstrued as an attack on anectodal data. A great deal of useful data can be obtained from the well-trained reporter of events occurring in his environment. Test pilot personnel have performed this function for many years. However, it is important to instruct the reporter upon what to report, have a reasonable sample of reports, and some internal consistency in reporting by each reporter.

B. Basic Studies in Sensory Deprivation and Sensory Reductions

The basic studies in this area may be divided into three categories. They are:

1. Absolute reduction of sensory information to the subject from the external world.

2. Reduced patterning of sensory input while retaining levels of input near normal.
3. Absence of change in the external environment or monotony.

Various studies reviewed by Holland (Ref. 13) on monitoring behavior have indicated that the probability of detecting a signal or target is increased with an increase in the number of signals presented. This, of course, indicates that monitoring performance (percent correct detections) is a function of sensory input. However, a recent preliminary study by Grodsky, et al (Ref. 14) indicated that high performance in monitoring situations is more closely related to shifts in subjective decision criteria or internal norms than time on the task (1 hour) or signal rate. If this be the case, then perhaps one effect of sensory deprivation or confinement is a shift in these internal norms thereby causing the noted decrements in performance.

Other studies have reported disturbances in perception in situations of perceptual deprivation (Ref. 15), (Ref. 16) and (Ref. 17). The term perceptual deprivation refers to those conditions where reduced patterning, imposed structuring and homogeneous stimulation are the environments in which the subjects are operating (Ref. 18). The results of these studies indicated that the disturbances are of the following types:

1. Deterioration in visual motor coordination.
2. Distortions in shape perception.
3. Accentuation of after images.
4. Perceptual lag.
5. Increase in perceived color saturation and contrast.

Though these results appear fairly serious the mode of producing sensory deprivation was quite artificial and drastic. In order to achieve the reduced sensory input, subjects were placed in sound attenuated cubicles, wore translucent goggles, cuffs and gloves, and had a masking noise introduced through earphones. The subjects remained under these conditions for periods as long as 6 days. Another result which was noted in these and other studies is a general decrease in the subject's efficiency of perceiving relevant stimuli. This might be explained again, in terms of a breakdown or shift in the internal norms of the subject. Another study (Ref. 19) has suggested that the major effects of confinement are in logical reasoning as found in complex tasks. Personality changes have been found in the above studies as well as in others which have been conducted. Further, Lilly (Ref. 5) has described the appearance of what has been termed "stimulus hunger". This is the apparent need of the subject for stimulation during the confinement situation to the extent of performing stimulus movements (motor and verbal) in order

to receive sensory stimulation.

C. Simulated Manned Space Flight Studies

A number of studies have been reported in this area which were concerned with the confinement of crews for extended periods of time during "simulated space flight missions". Burns, et al (Ref. 20) (Ref. 21) and (Ref. 22), has reported the results from an 8 day confinement study primarily concerned with the evaluation of a closed loop, solid chemical rebreathing system. Six naval enlisted personnel were confined in a 2-chambered compartment which collectively measured 12" 0" by 7' 2". The experimental design was concerned with such areas as: rigidity, time estimation, suggestibility, vigilance, etc. The major realistic task, however, was the monitoring and control of the atmospheric system while the other tasks were unrelated to the simulator or any simulated mission. Some of the pertinent results of the study are as follows:

1. Performance on tasks which were routine and without apparent consequence deterioriated rapidly. On those tasks on which feedback was available to the subject, high quality of performance was maintained for a considerably long period.
2. The subjects consistently overestimated the passage of time as the length of the confinement increased as compared to a group of control subjects.
3. The subject appeared to have a tendency toward increased suggestibility as the confinement continued as well as perceptual and personality changes.
4. The subjects apparently had a need and desire for consensual validation. That is, any cues as to diurnal variation, family, etc. seemed to reduce the effects of confinement.

Another series of space simulations reported the use of a two-man simulator (Ref. 23), (Ref. 24) and (Ref. 25). The two studies reported consisted of simulated missions of 14 and 30 days respectively. The cabin volume was approximately 380 cubic feet and was hermetically sealed. The 30 day study was conceptualized as an orbital mission with each orbit being 90 minutes in duration. However, the displays and crew tasks did not appear to have any relationship to such a mission except in the control of the environment. The results of this study indicated some decrements in performance without some of the more bizarre behavior noted in some of the more sensory deprived environment studies. Further, there were also shifts in proficiency as a function of the diurnal variation work-rest cycle of the crew.

Another study reported by Titov (Ref. 26) was a 15 day confinement study conducted in a completely sound attenuated chamber which contained a couch, refrigerator and display and control panel. Apparently from the description given all displays and control responses had a dynamic feedback. Titov also reported training in length of sleep (conditioning). Part of the experimental design also was the gradual decrease in the frequency of responses required. Though, Titov performed adequately for the 15 days and there was no permanent psychological effect, he does describe the intense boredom and the effect of the lack of any sound and his mode of combating it. Further, to demonstrate the marked effect the chamber had upon him, he described the device as the "chamber of horrors".

One additional study performed in the fall of 1961 utilized similar equipment to the equipment utilized in the present study. The mission was a 7-day lunar orbit mission utilizing 3-crew members (Ref. 27). The results indicated decrements in performance and behavioral effects in all three crew members. The trained test pilot member of the crew, however, was significantly less affected by the mission and his performance showed only slight decrements when compared to the other crew members. It was suggested that the lack of display-control response feedback, the duty cycle and crew composition, contributed to the noted decrements in the pilot performance. Further, somatic complaints occurred, due to the lack of a formalized in-flight exercise program.

D. Duty Cycle Studies

A number of pertinent studies are available in the duty-cycle literature which are pertinent to the present review. Hauty (Ref. 28) reported the results of a confinement study with a typical day-night duty cycle on the proficiency of performance. The results indicated that by use of a flight duty cycle which was different than the normal cycle of the subjects, performance proficiency was less than adequate. The results also indicated that the most wakeful period which may be likened to high performance can be shifted as much as 6 hours after approximately 3 days on the flight duty cycle. This demonstrates the importance of preflight adaptation to the duty cycle.

Ray, et al (Ref. 29), has concluded the following in a review of the duty cycle literature:

1. Physiological rhythms will show some but not complete adaptation to a non-24 hour cycle when the subject follows a typical schedule.
2. Individual variability as to adaptation and rate of adaptation is quite large.

3. For one week periods there does not appear to be significant performance variations provided the work-rest and sleep-wakefulness ratios are held constant. An exception to this may be on performance on vigilance tasks.
4. Measurement of performance on isolated tasks tend to yield little or no information relative to concurrent changes in complex tasks.

Two studies reported by Adams and Chiles (Ref. 30) and (Ref. 31) were concerned with human performance during lengthy confinement periods with various work-rest cycles. The first study (Ref. 30) consisted of testing 16 college students in a five man flight station mockup. A battery of five performance tasks, designed to evaluate mental computation, pattern discrimination, monitoring and vigilance, were utilized. The 16 subjects were divided into two test groups of 8 subjects each, and each group was tested separately for a period of 96 hours. Within a test group, the subjects were assigned to 4 schedule groups (A, B, C, and D) of 2-subjects each. Schedule group A worked during alternate 2-hour periods and those in groups B, C and D worked during alternate 4, 6, and 8-hour periods, respectively. Each subject received a total of 6 hours training prior to the onset of the experiment. The results of the study indicated that performance scores continued to improve throughout the 96 hours for each schedule group. Further, group differences in level of performance were not statistically significant. The authors stated that the data indicated that performance of the 8-hour group was poorer on those tasks which were less interesting. Subjective data further indicated that the 2 and 4-hour cycles were more favorable from a subjective adjustment than the 6 and 8 hour cycles.

The second study, a fifteen day confinement study, (Ref. 31) utilized a duty cycle of 4 hours on and 2 hours off. Further, this study utilized as subjects two operational B-52 crews. The first crew of 5 individuals (Group A) was a non-volunteer crew and had been recalled from annual leave to participate in the study and the second crew of 6 individuals (Group B) was a volunteer crew. The test facility contained approximately 1100 cubic feet. Five performance tasks similar to the earlier study were utilized. The two hour work period consisted of a 30-minute low performance period and a 90-minute high performance period. However, data was only collected during the high performance period. All subjects received 3 days training prior to the confinement. The results of the study are as follows:

1. The confinement conditions had less adverse effects on the well-motivated group than on the non-volunteer group.
2. There was a significant improvement in performing a learning task by the majority of subjects. Apparently, the duty-cycle utilized did not suppress acquisition of learned behavior.

3. The crew appeared to follow the same 24 hour periodicity which is found in other human studies. However, peak performance did tend to shift on some periods, and the highest level of autonomic activation did shift from the late evening to early morning hours dependent on the apparent shifts in the subjects frame of reference.

Chiles and Adams (Ref. 32) have recommended the following for duty cycles within aerospace systems:

1. Periods of wakefulness longer than 24 hours requiring performance of critical tasks are not feasible.
2. Six hours sleep per day are adequate for most individuals.
3. Sleep periods should not be less than 2 hours in duration.
4. Continuous performance of monotonous tasks should not exceed 2 hours.
5. Performance of active tasks may be extended to 10 hours.
6. A 5-day preadaptation period should be used to overcome initial sleep losses.

A recent study by Langdon & Hartman (Ref. 33) indicated the effect of sudden awakening upon performance. The study was performed on 5 airmen who were suddenly awakened and had to perform various psychomotor tasks. The results indicated that the differences between performance upon sudden awakening and when the operator is already awake is at the minimum of 25 per cent. There also appeared to be some positive adaptation in performance from day to day upon sudden awakening.

E. Physiological Studies

The preceding sections have described the effects on performance and behavior of confinement, sensory deprivation, and various duty cycles. Also of interest are the apparent physiological correlates of these conditions. In some cases due to the methodological problems of performance measures, a physiological measure might become a better indicator of stress or adaptation to a particular duty cycle than a performance measure.

Heron (Rev. 34) reported the results of pre-isolation and post-16 hours of isolation on electroencephlograph (EEG) tracings. The tracings indicated that slower frequencies appeared in the parieto occipital tracings after 16 hours and the tracings also indicated that for some hours after isolation the records did not return to normal. Further the author's impression of the EEG indicated that the subjects slept more during the early part of their stay in isolation and progressively less later in the period of confinement. Vernon, et al, (Ref. 35) reports that under conditions of 24, 48 and 72 hours of sensory deprivation that despite the fact that the subjects

ate well, there was a consistent loss of weight, averaging 2½ pounds. There was no apparent loss of strength with a hand dynamometer test except in the 72 hour group. Other measures such as heart rate and skin resistance have also been used in reduced sensory stimulation situations (Ref. 36).

Another mode of physiologically ascertaining stress and also adaptation to various duty cycles is by analysis of urinary excretions of subjects. There are any number of studies which indicate an increase in serum and urine 17-hydroxycorticosteroids immediately, prior to surgical operations and during psychological stress. Moncrief, et al (Ref. 37) found plasma corticosteroids 2 to 3 times higher just before surgery than 24 hours previously. Persky, et al (Ref. 38) studied 21 patients on a psychiatric service of a general hospital, all of whom had some degree of anxiety. Plasma hydrocortisone level and urinary hydroxycortiocosteroids excretions were 60 to 70 per cent greater in anxious subjects on a control day than in normal subjects. Elmadjian (Ref. 39) indicated that infantrymen during the Korean War showed elevated level of body fluid hydroxycortiocosteroids. The increase in serum free 17-hydroxycorticosteroids in dental patients due to apprehension prior to impaction has also been reported (Ref. 40). Mendelson, et al (Ref. 41) performed a detailed analysis of the catechol amine res[illegible] of 10 subjects isolated in a tank respirator. In comparison of pre-isolation, isolation and post-isolation excretion level, the authors found an increase in excretion levels followed by a decline after removal from the respirator. They also found a wide variability of response.

Seventeen-hydroxycorticosteroids (17-OHCS) also appear to have a pattern of excretion under normal diurnal conditions. Migeon, et al (Ref. 42) has demonstrated that normal subjects have been shown to have a maximum rate of excretion of urinary 17-OHCS between 0600 and 1200. After that time, the rate of excretion tends to decrease during the rest of the day and usually reaches minimal values during the night. The next morning it increases again.

Another facet of physiological factors which could influence performance concerns crew diet. Many studies are available indicating the acceptability of the diet and its effect on performance.

One additional physiological factor should be mentioned and that is the effect of reduced movement in limited spatial environments on the human musculature. There are also implications of these physiological effects during reduced gravity conditions (Ref. 43). A number of studies already mentioned have indicated musculature effects from confinement (Ref. 5), (Ref. 27) and (Ref. 35).

Appendix B

Sample Pages of Crew Operating Procedures & Flight Plans

Operator Procedures - Sample Page

Mission Phase Lunar Lift-Off and Ascent to Parking Orbit - SP.8.a.

Subject Preparation for Lunar Lift-Off

Time	Task/Subtask	Control Description	Display Indication	Operator Action	System Response/Summary Remarks
	1. Prepare Vehicle Propulsion Systems for Launch.				
	a. Arm Service Attitude Propulsion	Toggle Switch-Service ("Arm", "Safe")	Placard illuminates green when armed.	Set switch to "Arm" position.	
	b. Arm Service Vernier Propulsion	Toggle switch-Service ("Arm", "Safe")	Placard illuminates green when engine unit is armed.	Set switch to "Arm" position.	
	c. Arm Service Main Propulsion Engines No.'s 1 and 2.	Toggle switches on Main Propulsion Panel under SERVICE: 1. ARMED (Arm, Safe) 2. ARMED (Arm, Safe) 3. ARMED (Arm, Safe)	Placard illuminates green when respective engine units are armed.	Set no's. 1 & 2 engine switches to "Arm" position.	
	d. Arm Separation Bolts	Toggle switch on Main Propulsion Panel under SEPARATION: Bolts Armed ("Arm", "Safe")	Placard illuminates green when separation bolts are armed.	Set switch to "Arm" position.	Bolts explode automatically when vernier engines are advanced to full thrust (at lift-off, below).
	e. Set Thrust Throttle Control for Lunar Launch	Toggle switch LUNAR STAGE SERVICE STAGE ("Lunar", "Service")	Placard illuminates green according to which control mode is selected.	Set switch to "Service" position and observe illumination of placard.	

TIME	TASK/SUBTASK	CONTROL DESCRIPTION	DISPLAY INDICATION	OPERATOR ACTION	SYSTEM RESPONSE/SUMMARY REMARKS
	Establish Communications with Earth using VHF FM SYSTEM.	--	--	--	General: VHF FM SYSTEM used for communications (voice or television) and telemetry with Earth, from sometime prior to ascent to a range of 8,000 nautical miles from Earth. For ranges greater than 8,000 nautical miles the DEEP SPACE SYSTEM is used, and VHF FM SYSTEM is turned off.
	1. Turn on VHF FM Receiver.	3 position rotary selector switch,VHF FM SYSTEM-RECEIVER "Off" "1" "2"	--	Position switch from "Off" to "1" or "2"	Power is supplied to VHF FM receiver (1 or 2). The receiver is selected operates in the mode selected by the FUNCTION SELECT switches. Either receiver can be used with either transmitter.
	2. Turn on VHF FM Transmitter.	3 position rotary selector switch,VHF FM SYSTEM-TRANSMITTER "Off" "1" "2"	--	Position switch from "Off" to "1" or "2"	Power is supplied to VHF FM transmitter (1 or 2). The transmitter selected operates in the mode selected by the FUNCTION SELECT switches. Either transmitter can be used with either receiver.
	3. Select method of encoding telemetry data.	4 position rotary selector switch,GHF FM SYSTEM FUNCTION SELECT "Off" "PCM DIR" "PCM REC" "PAM"	--	Position switch to "PCM DIR" or "PCM REC" or "PAM"	Pulse code modulation data direct from source or from storage in the tape recorder is transmitted to earth via the VHF FM transmitter. Pulse amplitude modulation is a backup to PCM method. If PAM is used, the source of data (direct or from the tape recorder) is selected by another switch.
	4. Select source of transmitted data.	8 position rotary selector switch,VHF FM SYSTEM FUNCTION SELECT "Off" "Voice Rec" "TV DIR" "Voice Emer" "TV REC" "PAM/FM DIR" "Voice Dir" "PAM/FM REC"	--	Position switch to appropriate position.	Television data direct from scanning cameras or storage in the tape recorder is transmitted to Earth via the VHF FM transmitter. Television cameras are selected on the Navigator's CRT panel. TV output is transmitted directly, or from storage (operator controlled - described under tape recorders).

Flight Plan - Sample Page

MISSION PHASE: ASCENT

MISSION TIME	SYSTEM FUNCTION	COMMANDER POSITION	NAVIGATOR POSITION	ENGINEER POSITION
T+0.001 hrs. (00:00:04)	Boosted flight	Report system status and monitor flight parameters. Be ready to control spacecraft in case of an abort.	Report system status to Commander approx. every 30 sec. of boosted flight Monitor flight parameters and provide abort information.	Monitor system status and report (to Commander) only if unusual condition or malfunction is indicated.
T+0.002 hrs. (00:00:07)	Vehicle pitch over	Follow attitude commands.		
T+0.042 hrs. (00:02:32)	1st Stage Separation & 2nd Ignite	Standby to assume control in case of abort.	Call out boost sequencing and time.	Monitor Systems - Report (to Commander) only if unusual condition or malfunction indicated.
T+0.045 hrs. (00:02:42)	LES Jettison	Running account to ground monitor of flight parameters: Roll, Pitch, Yaw, Velocity altitude & acceleration.	Call out boost sequencing and time.	Monitor Systems - Report (to Commander) only if unusual condition or malfunction indicated.
T+0.140 hrs. (00:08:24)	2nd Stage Separation	Running account to ground monitor of flight parameters: Roll, Pitch, Yaw, Velocity altitude & acceleration.	Call out boost sequencing and time.	Monitor Systems - Report (to Commander) only if unusual condition or malfunction indicated.
T+0.193 hrs. (00:11:34)	3rd Stage Cut-Off	Running account to ground monitor of flight parameters: Roll, Pitch, Yaw, Velocity altitude & acceleration.	Call out boost sequencing; and time.	Monitor Systems - Report (to Commander) only if unusual condition or malfunction indicated.
T+0.194 hrs. (00:11:36)	System Check-out	Verify orbital insertion, parking orbit and status of all systems and equipment. Place Spacecraft on automatic stabilization.	Verify orbital insertion & status of all systems and equipment.	Monitor systems & verify status of all systems and equipment.
		Report personal physical status to Ground Monitor	Report personal physical status to Ground Monitor.	Report personal physical status to Ground Monitor

Appendix C
Pre-Flight and Inflight Exercises

I. Pre-Flight Exercises

A. Jumping Jacks - general warm-up exercise with the crew member standing erect and jumping with legs apart and simultaneously raising hands above the head and returning the legs together with hands at the side position. One hundred repetitions.

B. Rope Jumping - general warm-up, leg exercise and respiratory conditioning. The form used was:

15 seconds -- jump from both feet and then rest.
15 seconds -- jump one leg and then rest.
15 seconds -- jump other leg and then rest.
15 seconds -- stepping.

The time spent at each mode and the number of repetitions were to increase systematically during the 6 week preconditioning period.

C. Tiger Stretch - To strengthen back and abdominal muscles and as an aid for back pain and family elimination. The form was as follows: On all fours, move arms forward keeping knees fast and hollow the back. Then move arms toward the knees and arch back. It was repeated five times initially and then repeated 10 times.

D. Front and Back Bridges - to strengthen neck muscles, to aid in prevention of cervical pain, and withstand any possible whiplash forces. The front bridge is performed on all fours, forehead on the mat. The knees are raised and the body weight is supported on head and feet (the hands are used initially). Back bridges are performed on the back and the body weight is supported on the back of the neck and legs. Initially two front bridges and one back bridge was required, then the repetitions were increased to five of each.

E. Front Rolls - to stretch back muscles and aid in prevention of upper and lower back pain. The front roll is performed by squatting with hands on the mat, chin to chest, and weight on the back of neck. At start of roll the crew member grabbed his ankles and kept himself in a ball as much as possible Repeated five times initially and then increased to twelve repetitions.

F. Push-ups, leg raises, chins - for general conditioning of arms, legs, and abdominal muscles. The usual accepted form with the repetitions to be determined by each individual.

G. Swing Bell Exercise - to strengthen the muscles which act to balance the body and to coun eract positional fatigue. The form utilized consisted of utilizing a 15 pound weight between the hands instead of outside as in a dumbbell. All swing bell exercises were done in the same position with the crew member on his toes and with the toes spread a little less than that of shoulder width. The knees and hips were flexed to put the body in a starting position of precarious balance where it had to struggle to maintain an upright position. The first exercise from this position is the passing of the swing bell from the thigh position overhead to the back of the head and then to the thigh position. This gives anterior-posterior balance and a warm-up. The second exercise begins from the upright position, describes a circle overhead, keeping the arm relatively straight, and then is reversed. This is to exercise balance in all directions. The third exercise begins from the starting position and describes a circle in front of the body and then reverses the circle. The purpose of this exercise is to strengthen the muscles of lateral balance. The number of repetitions for each exercise and variation was about 10 to 12.

H. Pelvic Tilt - to strengthen muscles of the back and to counteract back pain from fatigue. The subject stands against the wall with the heels, buttocks, small of the back, shoulders, and head. The front of the pelvis is tilted so that the flat hand cannot slide between the wall and the small of the back. Started at 5 repetitions and increased to 10 repetitions.

I. Barbell Exercises - to develop body strength. First exercise is a modified clean. The knees are slightly bent, the barbell is lifted to the thigh rest position, and then to the chest position. It is then pressed overhead. Its purpose is to develop muscles of legs, back and arms. Two sets of twelve repetitions each. Second exercise is performed in a similar manner to the first but the weight is let down from the overhead position to behind the neck and pressed back up. The up and down portion of the exercise is repeated. Its purpose is to strengthen the triceps. Eventually 2 sets of 12 repetitions each. The third exercise is the bench press. It is performed while lying on the back on a low bench holding the barbell against the chest with both hands. The barbell is pressed upward and then lowered and repeated at least 10 times. The purpose of this exercise is to strengthen the muscles of the chest. The fourth exercise is the front curl. This exercise is performed by grasping the barbell with knuckles up and from the thigh rest position, the barbell is brought up to the chest.

This exercise is repeated in two sets of 10 repetitions each. The fifth exercise is a back curl and is performed similar to the front curl but with the barbell bar being held with knuckles downward.

The weight utilized for each exercise was determined by each crew member with the exception of the swing bell.

J. Running - for respiratory and normal physical conditioning. A normal running style was used with distance varying between one-half to one mile in 7 minutes or under.

II. Inflight Exercises

A. Sitting Position

1. Leg push - the exerciser is held by both hands and the right foot is pushed against the middle exerciser. Then the left foot, then both feet. About five repetitions of each.

2. Arm abduction - the exerciser is held by both hands and stretched in front of the chest. About five repetitions of each.

3. Arm abduction - the exerciser is held by both hands and the exerciser is stretched behind the neck with the head erect. About five repetitions of each (See Fig. 12).

4. Shoulder exercise - the exerciser is held by both hands and the exerciser is stretched behind the shoulders. About five repetitions of each.

5. Leg abduction - the exerciser is held in the left hand and on the right foot and the right foot is swung to the right and then the reverse is done. About five repetitions of each variation. (See Fig. 13).

6. Leg abduction - the exerciser is held in the right hand and on the right foot. The right foot is swung toward the midline of the body offering resistance with the right hand. The exercise is performed with the left hand and left foot. About 5 repetitions of each variation.

B. Standing Facing Forward

1. Pelvic tilt - performed in the same manner as described earlier.

2. Side bending - the exerciser is placed on the left foot and in the right hand and the subject bends to the right. The sequence is reversed to the right foot and left hand. About 5 repetitions. (See Fig. 14).

C. Standing Facing Port Side

1. Back extension - the exerciser is held in both hands and the subject stands on the middle of the exerciser with both feet. He does not bend his knees and he flexes from the hips. He strengthens hips and back. About 5 repetitions.

2. **Quarter knee bends** - the exerciser is held in both hands and the subject stands in the middle of the exerciser with both feet. Both knees are bent one quarter and then the knees are straightened. About 5 repetitions.

3. **Abdominal exercise** - draw in the abdominal muscles and hold for 6 seconds. Repeat about 5 times.

III. Substitute Inflight Exercise Program

A. Overhead Stretch

On 1. Reach overhead - rise on toes - hold 2 sec.

On 2. Touch toes

Repeat 10 times.

B. Sit on Seat

On 1. Raise legs

On 2. Legs apart - push feet against both bulkheads - hold 6 seconds

On 3. Legs together - Repeat 10 times.

C. Sit On Seat

Raise legs off deck

Go through stiff legged running motions - 1 minute.

D. 45° push-ups - Repeat 20 times

E. Standing - or sitting - hands behind neck

Bring elbows backward

Keep erect position - head up and chest up - inhale, hold 2 seconds, relax - Repeat 10 times.

F. 1/4 Knee bends -

Continue until all 5 min. of exercise period is consumed. (Gently, so as not to wake sleeper). Report any troubles due to space limitations.

IV. Howard Step Test Protocol

A. Equipment

1. Platform - approximately 19 1/2 inches high, non-skid type, top area 2 feet square.

2. Metronome capable of 1 beat/second.

3. Stop watch with sweep second hand.

4. Hand counter to record number of steps climbed.

B. Techniques

1. Subject dressed in underwear, socks and tennis shoes.

2. Brief subject on how to accomplish test. The physician demonstrates to the subject that he (the subject) was to step upon the platform during the first second, step down during the second second, step up during the third second, and continue this performance for 5 minutes. The subject should be advised that he might crouch forward as low as he chooses when stepping up, thus negating the necessity of coming to a full upright position on the step. (If this is not done, many subjects will fall behind the metronome if they are directed to come to an erect position on the steps.) The subject should be further advised that if he is unable to keep up with the metronome, he is to continue as near as possible to a metronome pace. If the subject stumbles or falls, he should be encouraged to continue the test if he is uninjured.

3. After these instructions, the metronome should be started and as soon as the subject begins his first step, the stop watch is started. During the test no encouragement or directions other than the above should be given. At the end of five minutes the subject should immediately sit down. The physician should perform the following:

   a. Record pulse during the following three time periods. The end of the test being considered time zero; from 1 to 1 1/2 minutes, from 2 to 2 1/2 minutes and from 4 to 4 1/2 minutes.

   b. All pulses are recorded by precordial auscultation.

   c. The recording of the pulses ends the tests.

C. **Example Record**

1. Pulse 1 to 11/2 minutes after test = 79 x 2 = 158 beats/min.

2. Pulse 2 to 21/2 minutes after test = 73 x 2 = 146 beats/min.

3. Pulse 3 to 31/2 minutes after test = 64 x 2 = 128 beats/min.

Total Pulse = 432

Number of steps climbed = 111

D. **Scoring**

1. It is assumed that a high postexercise pulse is believed to reflect poor physical fitness and a low number of step-ups reflects poor subject participation.

2. The total step-up value (5) is divided by the total pulse value (P) multiplied by 150 to give the final Harvard step test score. Thus,

$$\frac{S}{P} \times 150 = \text{score} = \frac{111}{432} \times 150 = 39$$

3. All subjects should be able to perform for five minutes. The average step score should be 52.8. An acceptable range is 45.00 to 100.00

E. **Interpretation**

An above average score is desirable and a crude example of better than physical fitness. A narrative of the subject's performing this test should also be required.

Appendix D

Lunar Mission Simulation Equations

LUNAR MISSION SIMULATION EQUATIONS

General Assumptions

1. All cross products of inertia = 0 = $I_{YZ} = I_{XY} = I_{XZ}$ (principal axis system).
2. $I_{YY} = I_{ZZ}$.
3. $\dot{I}$ terms = 0.
4. θ = pitch angle $= \int \dot{\theta}\, dt$

   $\dot{\theta}$ = pitch rate $= \int \ddot{\theta}\, dt$

   ψ = yaw angle $= \int \dot{\psi}\, dt$

   $\dot{\psi}$ = yaw rate $= \int \ddot{\psi}\, dt$

   ϕ = roll angle $= \int \dot{\phi}\, dt$

   $\dot{\phi}$ = roll rate $= \int \ddot{\phi}\, dt$

Phase I--Ascent

1. $$\dot{v} = -\dot{\psi} V_T + \frac{QS}{M_{Bi}} C_{Y\beta}\,\beta - \frac{T_{Bi}}{M_{Bi}} \delta_{YB}.$$

2. $$\dot{w} = \dot{\theta} V_T + \frac{QS}{M_{Bi}} C_{Z\alpha}\,\alpha + \frac{T_{Bi}}{M_{Bi}} \delta_{PB}.$$

3. $$\ddot{\phi} = \frac{T_{Bi} R_{Bi}}{I_{XX_{Bi}}} \delta_{RB} - K_1 \dot{\phi}$$

4. $$\ddot{\theta} = \frac{QSd}{I_{YY_{Bi}}} C_{m\alpha}\,\alpha + \frac{T_{Bi} L_{Bi}}{I_{YY_{Bi}}} \delta_{PB}.$$

5. $$\ddot{\psi} = \frac{QSd}{I_{ZZ_{Bi}}} C_{N\beta}\,\beta + \frac{T_{Bi} L_{Bi}}{I_{ZZ_{Bi}}} \delta_{YB}$$

6. $\dot{\alpha} = \frac{\dot{w}}{V_T}$ $\qquad \alpha = \int \dot{\alpha}\, dt.$

7. $\dot{\beta} = \frac{\dot{v}}{V_T}$ $\qquad \beta = \int \dot{\beta}\, dt.$

Function Generated Parameters:

$$V_T,\ \frac{QS}{M_{Bi}}\ C_{Y\beta}\ ,\ \frac{QS}{M_{Bi}}\ C_{Z\alpha}\ ,\ \frac{T_{Bi}}{M_{Bi}}\ ,\ \frac{T_{Bi}\, R_{Bi}}{I_{XX_{Bi}}}\ ,$$

$$\frac{QSd}{I_{YY_{Bi}}}\ C_{m\alpha}\ ,\ \frac{QSd}{I_{ZZ_{Bi}}}\ C_{N\beta}\ ,\ \frac{T_{Bi}\, L_{Bi}}{I_{YY_{Bi}}}\ ,\ \frac{T_{Bi}\, L_{Bi}}{I_{ZZ_{Bi}}}\ .$$

It was assumed that $C_{Y\beta} = C_{Z\alpha}$ and that $C_{m\alpha} = C_{Z\alpha}\,(X_{CP} - X_{CG})$.

Boost vehicle was a typical "Nova".

First stage: 8 F-1, Thrust = 12,000,000 lb.

Second stage: 8 J-2, Thrust = 1,600,000 lb.

Third stage: 2 J-2, Thrust = 400,000 lb.

Phase II--Earth Parking Orbit

$$\ddot{\phi} = \frac{M_{XC}}{I_{XXB3}}$$

$$\ddot{\theta} = \frac{M_{YC}}{I_{YYB3}}$$

$$\ddot{\psi} = \frac{M_{ZC}}{I_{ZZB3}}$$

M_{XC}, M_{YC}, M_{ZC} are moments due to attitude jets.

Autopilot:

$$\epsilon_\theta = (\theta_C - \theta) - K_{R\theta}\,\dot{\theta}$$

$$\epsilon_\psi = (\psi_C - \psi) - K_{R\psi}\,\dot{\psi} - K_I \epsilon_\phi$$

$$\epsilon_\phi = (\phi_C - \phi) - K_{R\phi}\,\dot{\phi} + K_2 \epsilon_\psi .$$

Phase III--Translunar Insertion

$$\dot{U} = \frac{T_{B3}}{M_{B3}} \qquad u = \int \dot{u}\, dt = (\Delta V \text{ added})$$

$$\ddot{\phi} = \frac{M_{XC}}{I_{XXB3}}$$

$$\ddot{\theta} = \frac{M_{YC}}{I_{YYB3}}$$

$$\ddot{\psi} = \frac{M_{ZC}}{I_{ZZB3}}$$

Phase IV--Translunar Coast

Control equations

Autopilot:

$$\epsilon_\theta = (\theta_C - \theta) - K_{R\theta}\,\dot{\theta}$$

$$\epsilon_\psi = (\psi_C - \psi) - K_{R\psi}\,\dot{\psi} - K_I \epsilon_\phi$$

$$\epsilon_\phi = (\phi_C - \phi) - K_{R\phi}\,\dot{\phi} + K_2 \epsilon_\psi .$$

$$\delta_{PV} = K_\theta (\theta_C - \theta) - K_{\dot{\theta}}\,\dot{\theta}$$

$$\delta_{YV} = K_\psi (\psi_C - \psi) - K_{\dot{\psi}}\,\dot{\psi}$$

$$\delta_{RV} = K_\phi (\phi_C - \phi) - K_{\dot{\phi}}\,\dot{\phi} .$$

Manual:

$\epsilon_\theta, \epsilon_\psi, \epsilon_\phi$ = stick or pedal deflections

$\delta_{PV}, \delta_{YV}, \delta_{RV}$ = stick or pedal deflections with gain change.

Phase V--Midcourse Corrections (3).

$$\dot{u} = \frac{T_{SC}}{M_{SC}}$$

$$\Delta V = \int \dot{u}\, dt$$

$$\ddot{\phi} = \frac{M_{SC\phi}}{I_{XXSC}}$$

$$\ddot{\theta} = \frac{M_{SC\theta}}{I_{YYSC}}$$

$$\ddot{\psi} = \frac{M_{SC\psi}}{I_{ZZSC}}$$

where

$$M_{SC\phi} = M_{XC} + T_V R_{SC} \delta_{RV}$$

$$M_{SC\theta} = M_{YC} + T_V L_{SC} \delta_{PV}$$

$$M_{SC\psi} = M_{ZC} + T_V L_{SC} \delta_{YV}$$

L_{SC}, R_{SC} are moment arms

$$T_{SC} = T_V + T_{S1} + T_{S2}$$

Phase VI--Lunar Orbit Insertion

$$\dot{u} = \frac{T_{SC}}{M_{SC}} \qquad \Delta V = \int \dot{u}\, dt$$

$$\ddot{\phi} = \frac{M_{SC\phi}}{I_{XXSC}}$$

$$\ddot{\theta} = \frac{M_{SC\theta}}{I_{YYSC}}$$

$$\ddot{\psi} = \frac{M_{SC\psi}}{I_{ZZSC}}$$

Phase VII--Lunar Orbit

Automatic.

Phase VIII--Lunar Deorbit

$$\dot{u} = \frac{T_{SC}}{M_{SC}} \qquad \Delta V = \int \dot{u}\, dt$$

$$\ddot{\phi} = \frac{M_{SC\phi}}{I_{XXSC}}$$

$$\ddot{\theta} = \frac{M_{SC\theta}}{I_{YYSC}}$$

$$\ddot{\psi} = \frac{M_{SC\psi}}{I_{ZZSC}}$$

Phase IX--Lunar Landing Coast

Automatic--control equations

Phases X and XI--Lunar Landing Braking and Terminal

See Fig. C-1.

$$\ddot{\phi} = \frac{M_{SC\phi}}{I_{XXSC}}$$

$$\ddot{\theta} = \frac{M_{SC\theta}}{I_{YYSC}}$$

$$\ddot{\psi} = \frac{M_{SC\psi}}{I_{ZZSC}}$$

$$\dot{V}_f = -\frac{T_{SC}}{M_{SC}} \cos \alpha + g_m \sin \gamma_T$$

where

$$\alpha = \bar{\theta}_A + \bar{\gamma}_T$$

$$\gamma_T = \bar{\gamma}_T + \phi_m$$

$$\phi_m = \frac{X_m}{R_m}$$

$$\bar{\theta}_A = \bar{\theta}_P + \Delta\theta$$

$$V_F \dot{\bar{\gamma}}_T = \frac{T_{SC}}{M_{SC}} \sin \alpha - g_m \cos \gamma_T$$

$$\dot{h}_m = V_f \sin \gamma_T$$

$$\dot{X}_m = V_f \cos \gamma_T$$

$$h_m = \int \dot{h}_m \, dt + h_{mo}$$

$$X_m = \int \dot{X}_m \, dt + X_{mo}$$

Phase XII--Lunar Ascent (powered)

$$\dot{u} = \frac{T_{SC}}{M_{SC}} \qquad u = \int \dot{u} \, dt$$

$$\ddot{\phi} = \frac{M_{LC\phi}}{I_{XXLC}}$$

$$\ddot{\theta} = \frac{M_{SC\theta}}{I_{XXSC}}$$

$$\ddot{\psi} = \frac{M_{SC\psi}}{I_{ZZSC}}$$

θ_C and V_T are functioned generated.

Phase XIII--Lunar Ascent Coast

Automatic

Phase XIV--Rendezvous

$$\ddot{X} = -\omega^2 X + \frac{T_X}{m}$$

$$\ddot{Y} = 2\omega\dot{Z} + \frac{T_Y}{m}$$

$$\ddot{Z} = 3\omega^2 Z - 2\omega\dot{Y} + \frac{T_Z}{m}$$

X = lateral displacement (+ to left)

Y = fore-aft displacement (+ aft)

Z = vertical displacement (+ above)

m = vehicle mass

T = vehicle thrust

ω = angular velocity of circular orbit

Phase XV--Lunar Orbit

Automatic

Phase XVI--Transearth Insertion

Same as Phase III.

Phase XVII--Transearth Midcourse Corrections

Same as Phase V.

Phase XVIII--Re-entry

$$F_{xa} = -C_D S (\Delta Q)$$

$$F_{xg} = -M_{LC} g_e (\Delta \gamma)$$

$$F_{za} = C_L S \left[(Q + \Delta Q) \sin \phi_C (\Delta \phi) - (\Delta Q) \cos \phi_C \right]$$

$$F_{zg} = -M_{LC} g_e \gamma_p (\Delta \gamma)$$

$$\Delta \phi = |\phi| - |\phi_C|$$

$$\Delta Q = 2 \frac{Q}{V_T} (\Delta V)$$

$$\Delta \dot{V} = \frac{1}{M_{LC}} (F_{xa} + F_{xg})$$

$$\Delta V = \int \Delta \dot{V} \, dt$$

$$V_f = V_T + \Delta V$$

$$\Delta \dot{\gamma} = \frac{1}{M_{LC} V_T} (F_{za} + F_{zg})$$

$$\Delta \gamma = \int \Delta \dot{\gamma} \, dt$$

$$\gamma_f = \gamma_p + \Delta \gamma$$

$$\dot{h}_e = V_f (\Delta \gamma) + \gamma_p (\Delta V)$$

$$h_e = \int \dot{h}_e \, dt$$

$$\dot{p} = \frac{1}{I_{XX}} (M_{XC} - C_1 Q p), \quad p = \int \dot{p} \, dt$$

$$\dot{q} = \frac{1}{I_{YY}} (M_{YC} - C_2 Q q), \quad q = \int \dot{q} \, dt$$

$$\dot{r} = \frac{1}{I_{XY}} (M_{ZC} - C_3 Q r), \quad r = \int \dot{r} \, dt$$

$$\phi = \int p \, dt, \quad \theta = \int q \, dt, \quad \psi = \int r \, dt$$

SYMBOLS

V_T = Book trajectory velocity

V_f = Total velocity

w = Perturbation velocity, X direction

v = Perturbation velocity, Y direction

$\dot{w}$ = Perturbation velocity, Z direction

γ_T = Book trajectory flight path angle, earth/moon ref system

γ_l = Book trajectory flight path angle, local horizontal

$\Delta\gamma$ = Perturbation flight path angle

θ_T = Arbitrary attitude reference, earth/moon reference system

θ_C = Arbitrary attitude reference, vehicle reference system

θ = Vehicle pitch attitude

ψ_C = Command yaw attitude

ψ = Vehicle yaw attitude

ϕ = Vehicle roll attitude

ϕ_C = Command roll attitude

α = Angle of attack

β = Side slip angle

R = Vehicle body angular rate, roll

q = Vehicle body angular rate, pitch

r = Vehicle body angular rate, yaw

δ = Control deflection

Q = Dynamic pressure (from book trajectory)

S = Vehicle reference area

d, D = Vehicle reference length

M = Vehicle mass

I_{XX} = Vehicle roll moment of inertia

I_{YY} = Vehicle pitch moment of inertia

I_{ZZ} = Vehicle yaw moment of inertia

M_{iC} = Control moment, reaction jets

T_B, T_V,
T_{S1}, T_{S2},
T_{SM} = Control thrust, booster, vernier, J-2, LR 11s, service main

R = Roll control moment arm

L = Pitch/yaw control moment arm

$C_{y\beta}$ = Booster aero derivative, side force

$C_{n\beta}$ = Booster aero derivative, yaw moment

$C_{n\dot{\psi}}$ = Booster aero derivative, yaw rate damping

$C_{\epsilon\alpha}$ = Booster aero derivative, pitch force

$C_{m\alpha}$ = Booster aero derivative, pitch moment

$C_{m\dot{\theta}}$ = Booster aero derivative, pitch rate damping

C_D = Re-entry vehicle drag coefficient

C_L = Re-entry vehicle lift coefficient

K's = Autopilot displacement gains

K_R's = Autopilot rate gains

ϵ = Control signal

g_m = Gravity, moon

g_e = Gravity, earth

r_m = Radius, moon

r_e = Radius, earth

X_m = Range-to-go, moon

X_e = Range-to-go, earth

h_m = Vehicle altitude, moon

h_{mT} = Trajectory altitude, moon

h_e = Vehicle altitude, earth

h_{eT} = Trajectory altitude, earth

G = Load factor, earth re-entry

Subscripts:

B_i	=	Booster stage $i = 1, 2, 3$
PB, YB, RB	=	Booster engines
PV, YV, RV	=	Verniers
SC	=	Spacecraft
LC	=	Re-entry vehicle
T	=	Book trajectory

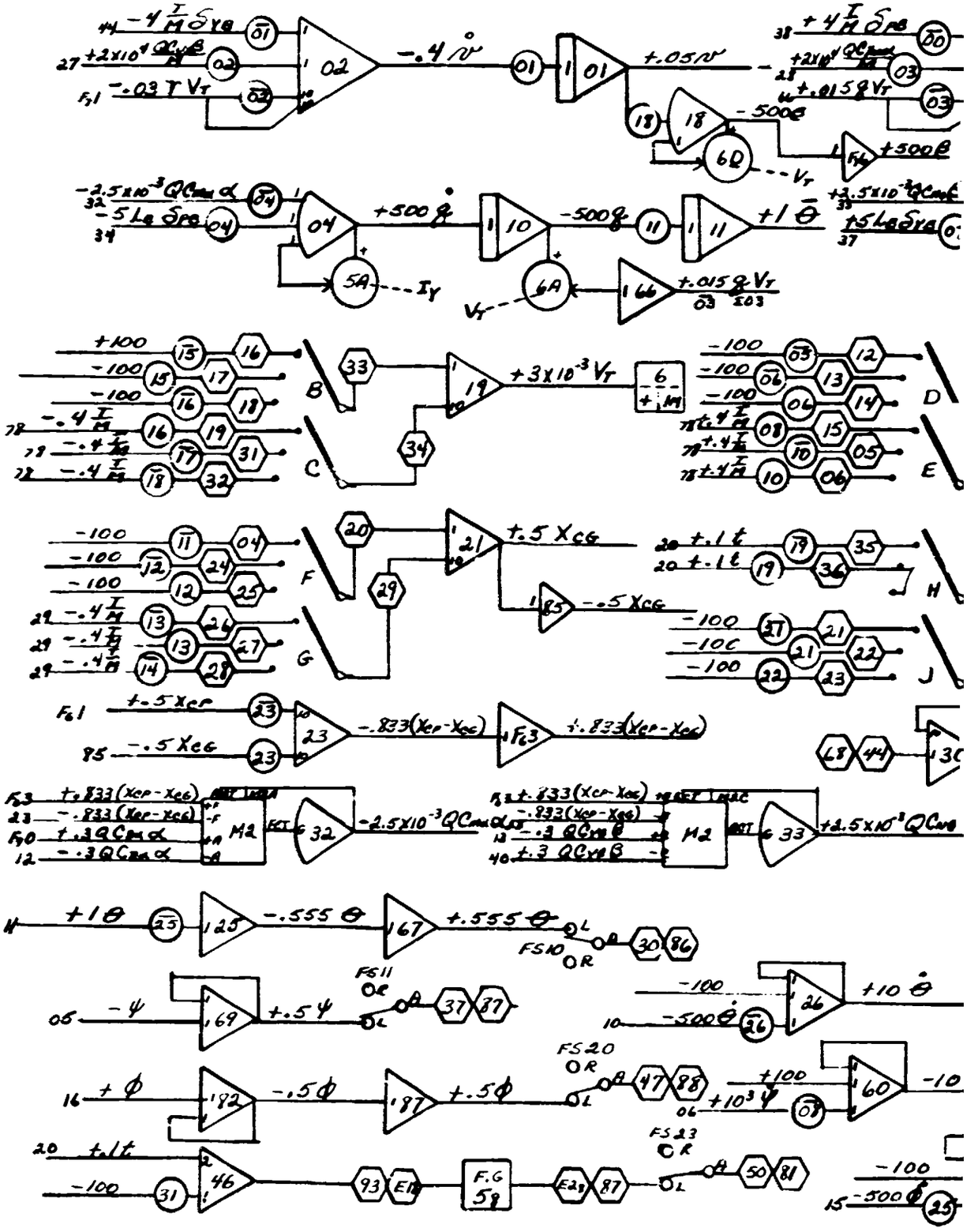
Appendix E

Analog Schematics

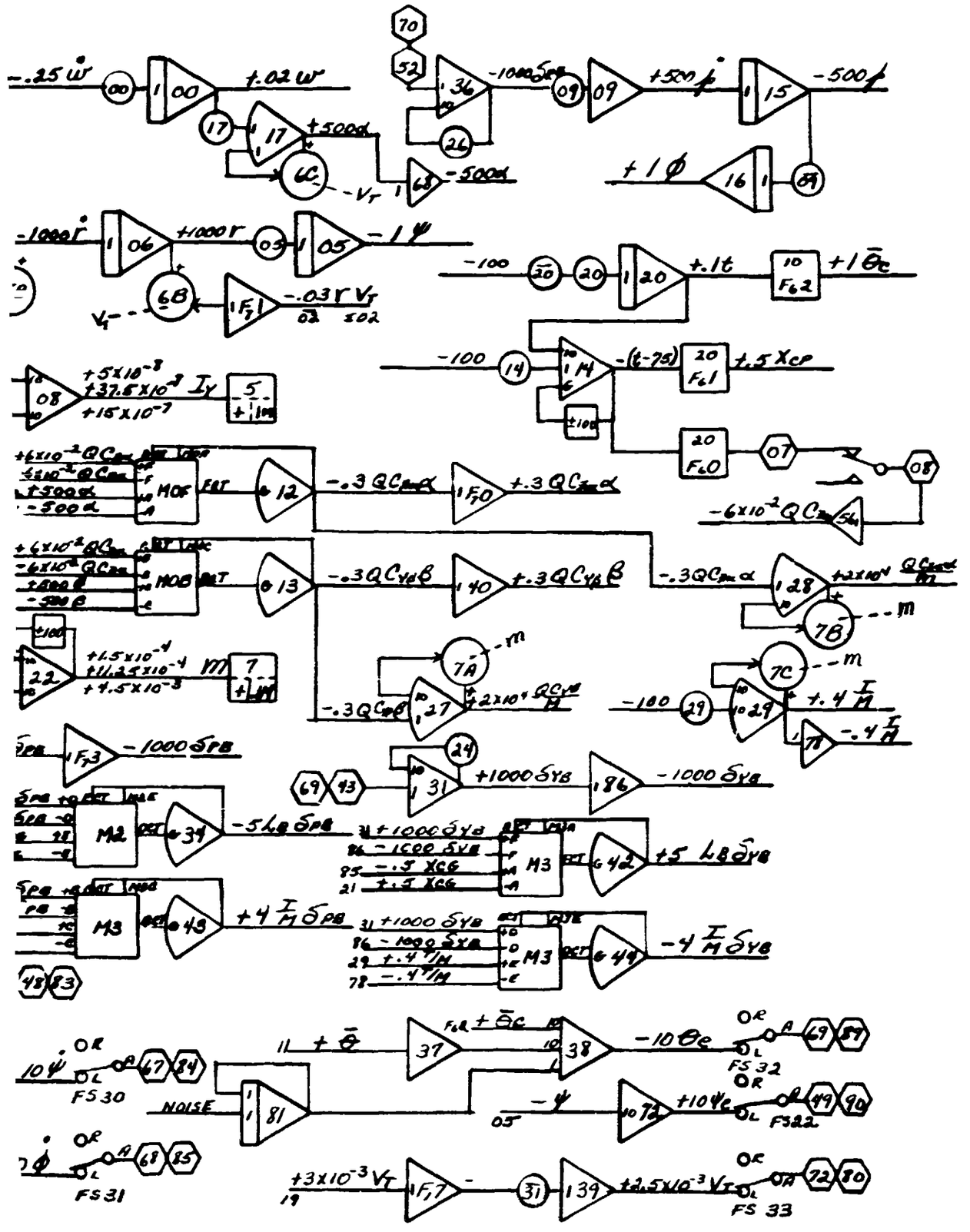
for

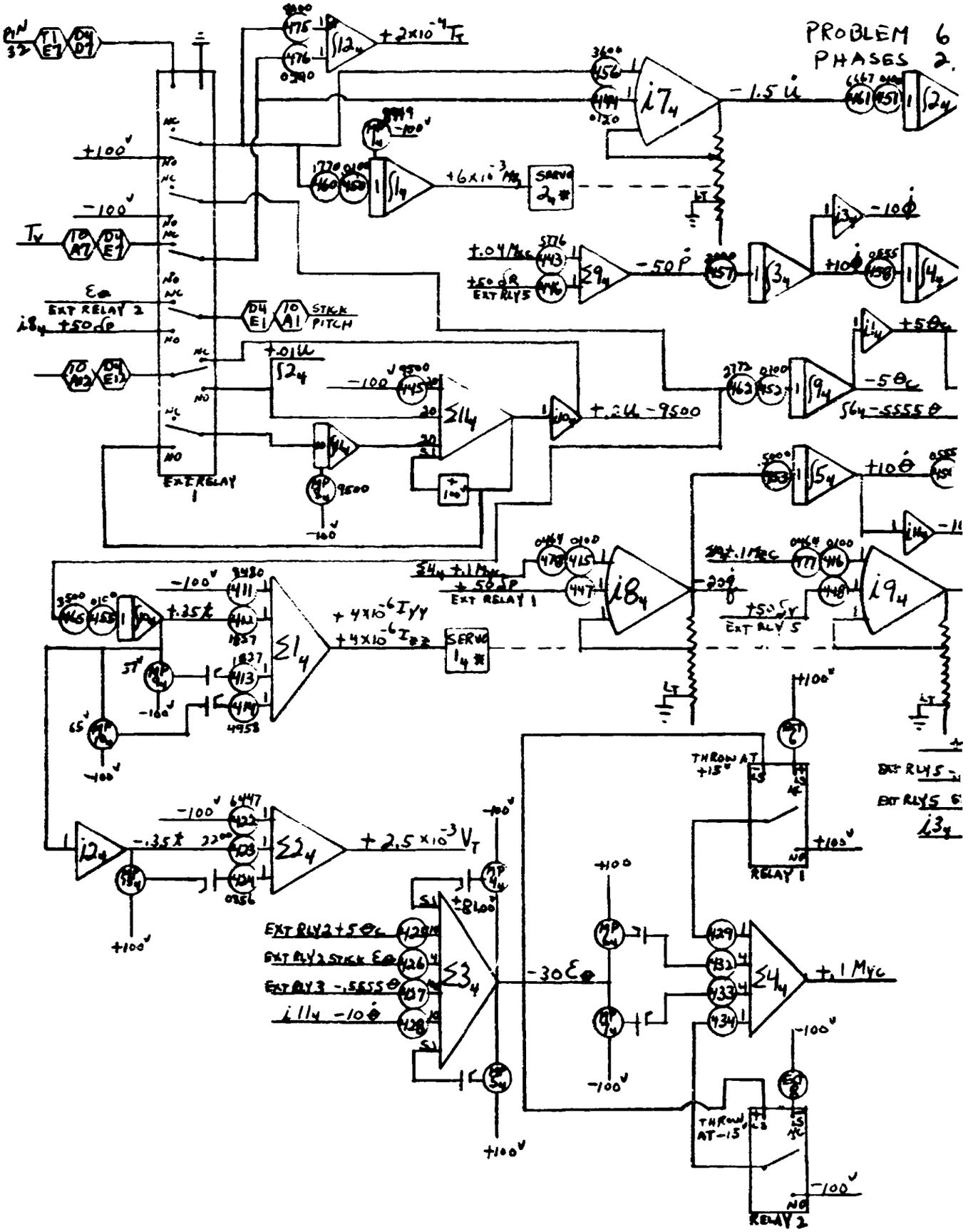
Lunar Mission Simulation

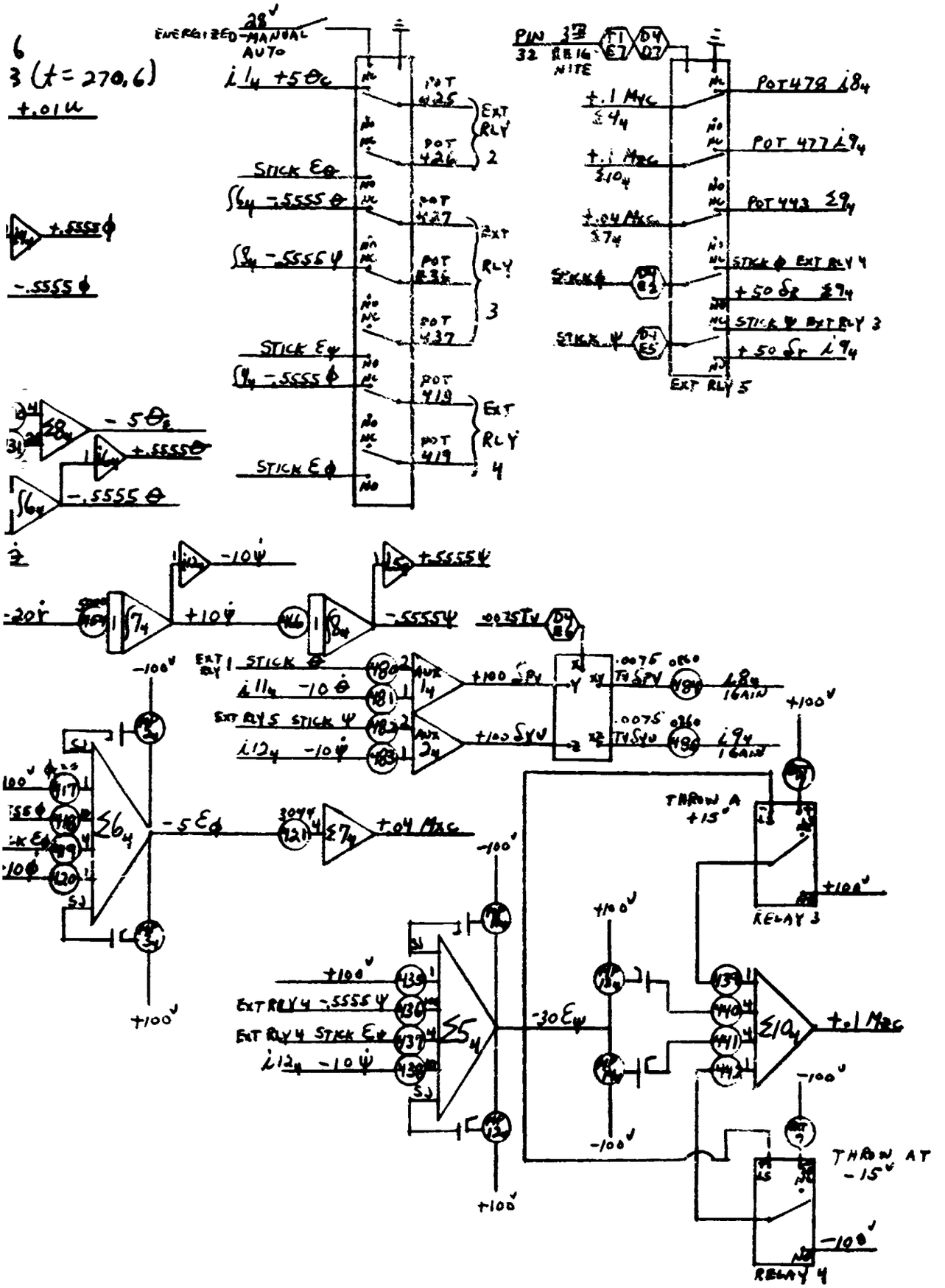
LMS P

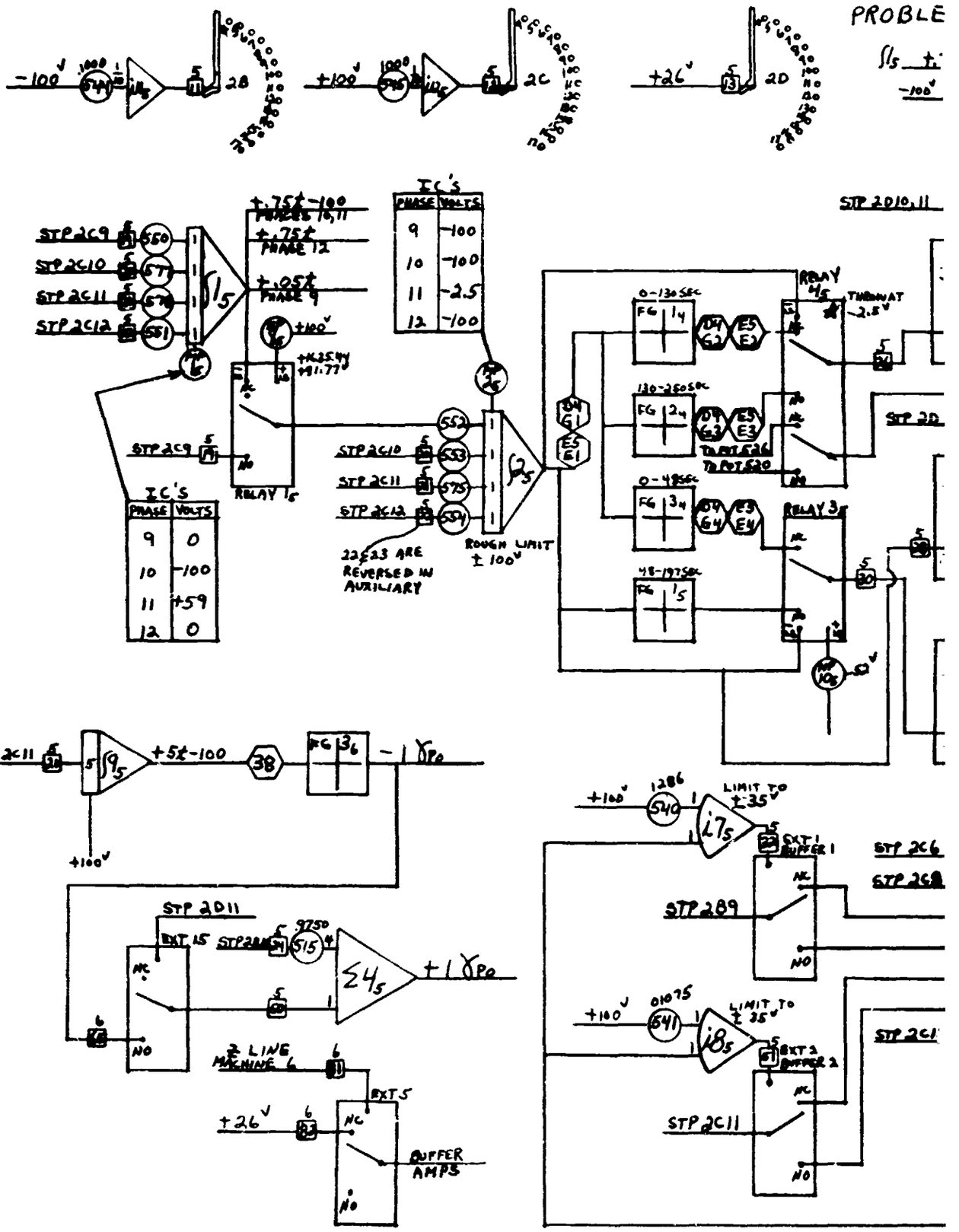

02
01
01
18
18
6Q
04
10
11
11
5A
6A
19
33
34
B
C
D
E
20
29
21
23
F
G
H
J
M2
M2
32
33
125
167
169
182
187
26
60
46
F.G
5g
FS10
FS11
FS20
FS23
OR
OR

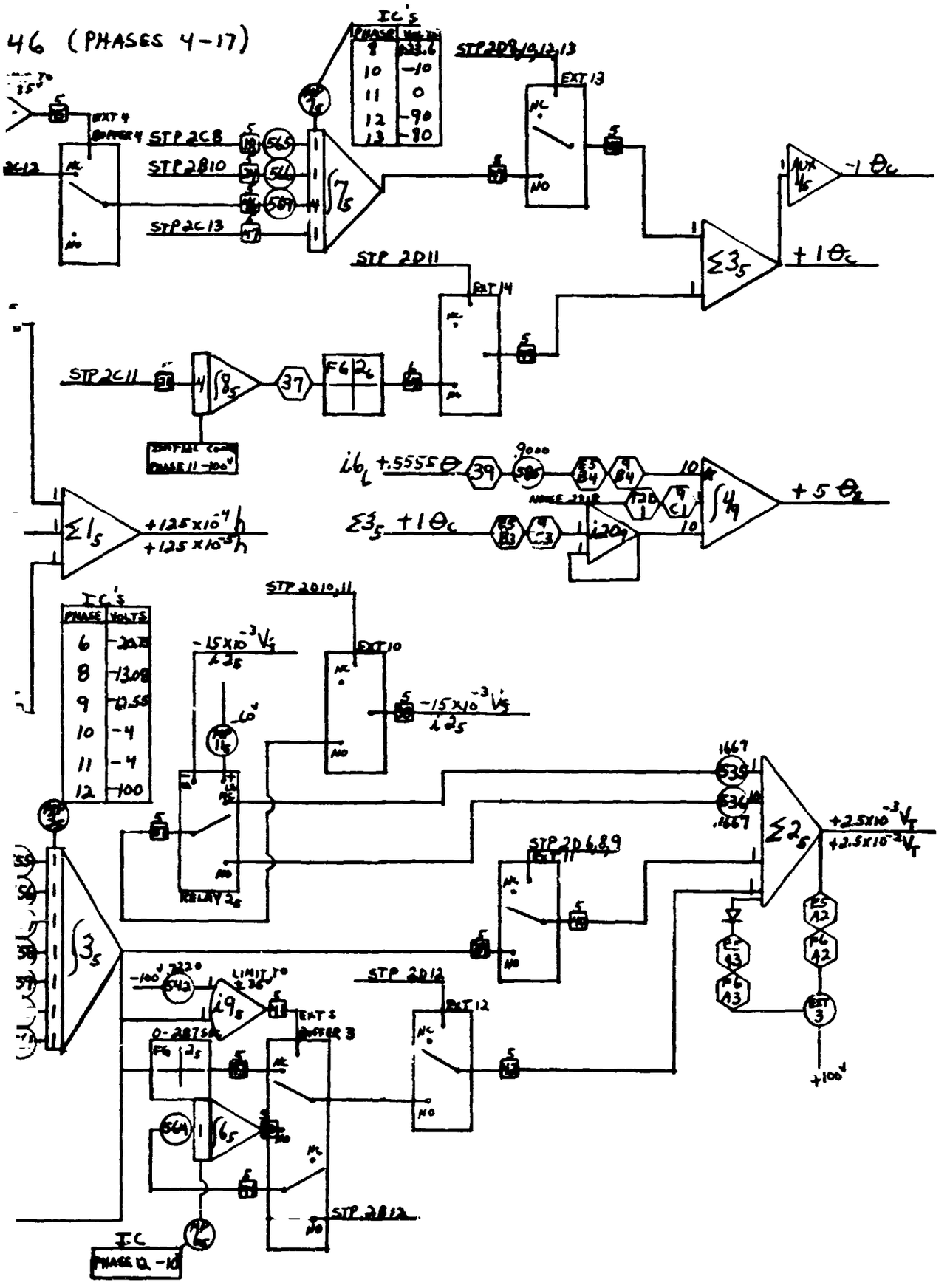
E I


-.25 ẇ
+.02 w
+500 α
-500 α
-1000 r
+1000 r
-1 ψ
-.03 r V_T
+1 θ_c
+.1 t
-(t-75)
+.5 X_cp
-.3 QC_mα
+.3 QC_mα
-6x10^-2 QC_mα
-.3 QC_YβB
+.3 QC_YβB
+2x10^4 QC_mα/M
-m
-1000 δ_PB
+1000 δ_YB
-5 L_β δ_PB
+5 L_β δ_YB
+4 I/M δ_PB
-4 I/M δ_YB
+1 φ
-10 θ_c
+10 ψ_c
+3x10^-3 V_T
+2.5x10^-3 V_T
NOISE
FS 30
FS 31
FS 32
FS 33
FS 22

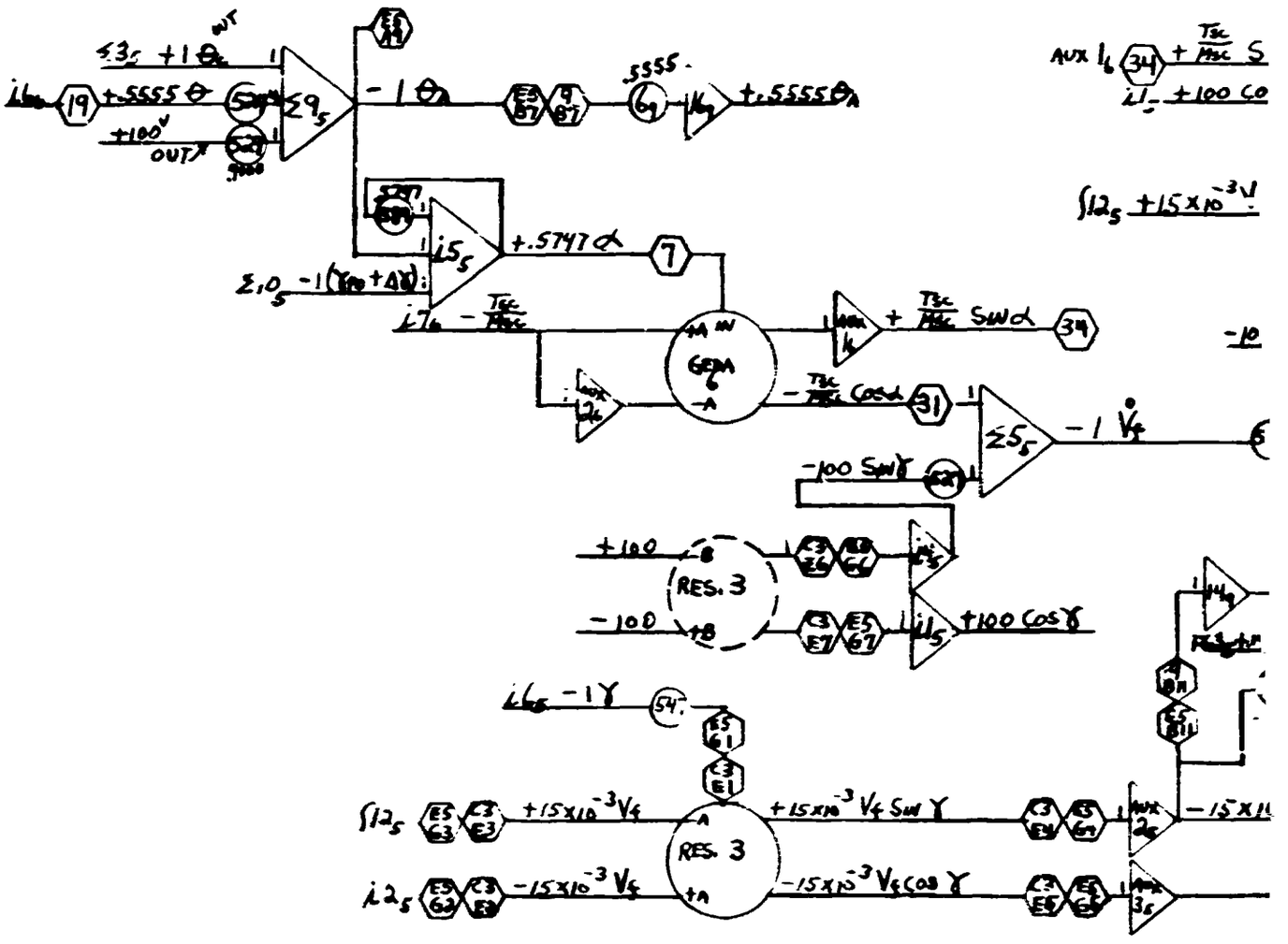

PROBLEM 6
PHASES 2.
+100
-100
EXT RELAY 1
EXT RELAY 2
STICK PITCH
THROW AT +15°
THROW AT -15°
RELAY 1
RELAY 2
EXT RLY5
EXT RLY5 6
i3₄

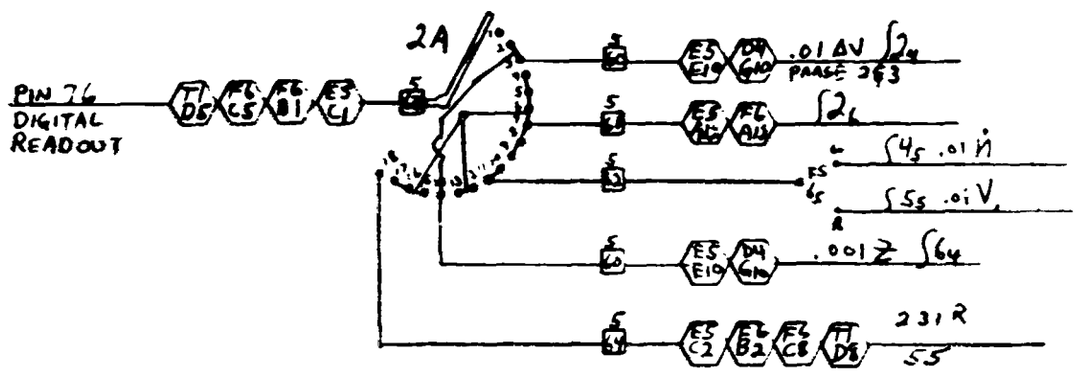

6
3 (t = 270.6)
+.01 in
28 V
ENERGIZED
MANUAL
AUTO
PIN 32
RR 16 NITE
EXT RLY 2
EXT RLY 3
EXT RLY 4
EXT RLY 5
STICK Eθ
STICK Eψ
STICK Eφ
STICK φ
STICK ψ
POT 425
POT 426
POT 427
POT 436
POT 437
POT 419
POT 478
POT 477
POT 443
+.5555 φ
-.5555 φ
-5θc
+.5555 θ
-.5555 θ
-10ψ̇
+10ψ̇
-20ṙ
-.5555ψ
+.5555ψ
.0075 TVδPY
.0075 TVδYU
+100 δPY
+100 δYU
+50 δq
+50 δr
-5Eφ
-30Eψ
+.04 Max
+.1 Max
+100 V
-100 V
THROW A +15°
THROW AT -15°
RELAY 3
RELAY 4


PROBLE
-100V
+100V
+26V
28
2C
2D
STP 2C9
STP 2C10
STP 2C11
STP 2C12
IC's
PHASE
VOLTS
ROUGH LIMIT ± 100V
RELAY 1S
RELAY 4S
RELAY 3S
THERMAT -2.5V
0-130 SEC
130-260 SEC
0-495 SEC
48-1975 SEC
22 & 23 ARE REVERSED IN AUXILIARY
STP 2D10,11
STP 2D
STP 2C11
+5t-100
-1 γPo
+1 γPo
STP 2D11
EXT 1S
2 LINE MACHINE 6
EXT 5
BUFFER AMPS
LIMIT TO ±35V
EXT 1 BUFFER 1
EXT 2 BUFFER 2
STP 2C6
STP 2C8
STP 2C9
STP 2C11

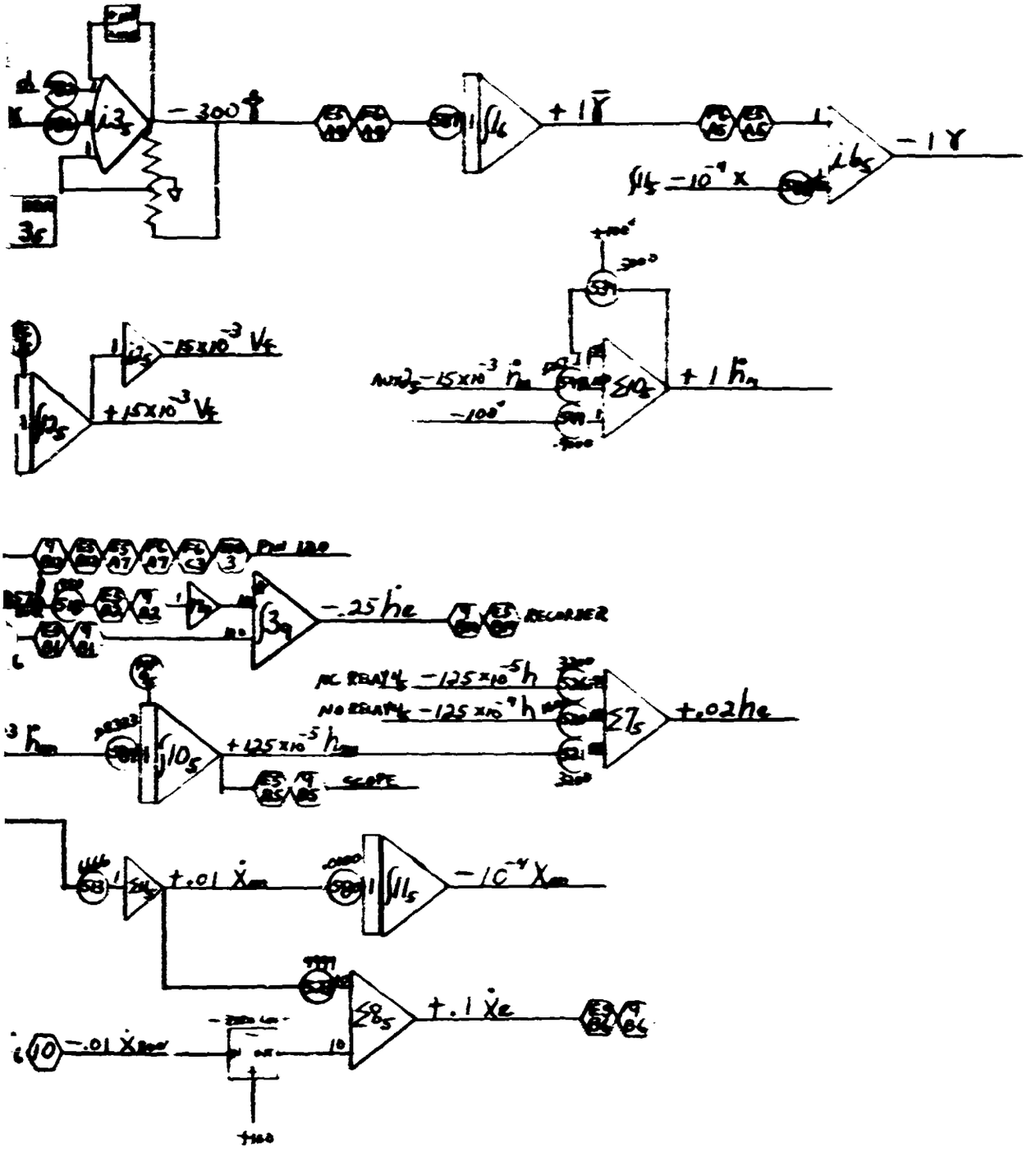

46 (PHASES 4-17)
IC's
PHASE
10 -10
11 0
12 -90
13 -80
STP 2D9,10,12,13
EXT 13
STP 2C8
STP 2B10
STP 2C13
STP 2D11
EXT 14
STP 2C11
37
+1θc
-1θc
+5θc
+125x10⁻⁴h
+125x10⁻³h
IC's
PHASE VOLTS
6 -20
8 -13.08
9 -12.55
10 -4
11 -4
12 -100
STP 2D10,11
EXT 10
-15x10⁻³Vs
-15x10⁻³Vs
RELAY 26
STP 2D6,8,9
EXT 11
STP 2D12
EXT 12
EXT 3
+100V
+2.5x10⁻³VT
+2.5x10⁻²VT
.1667
.1667
-100
LIMIT TO ±36V
EXT 5 BUFFER 3
0-28750
STP 2B12
IC
PHASE 12 -10

PROBLEM

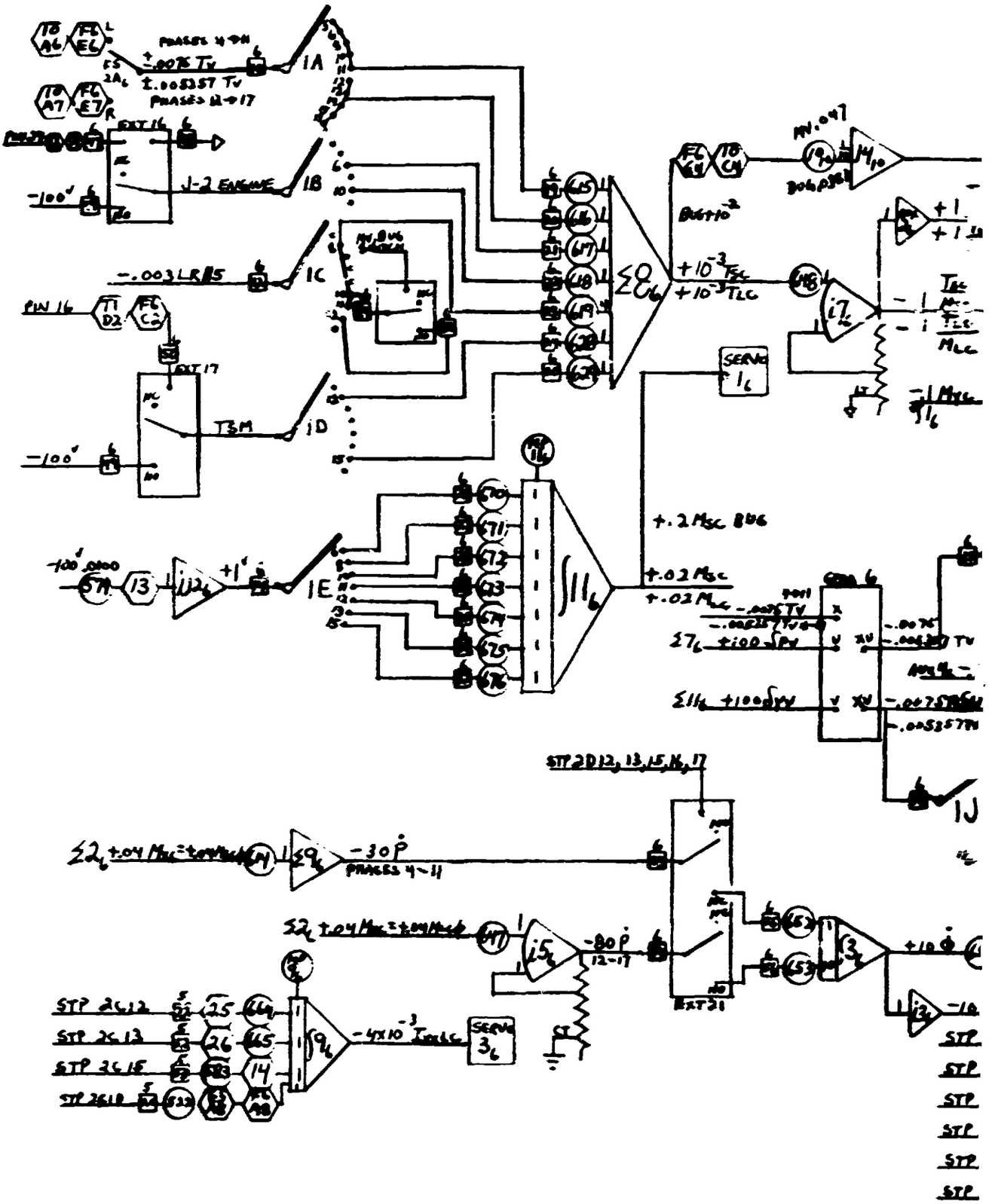

RES. 3
RES. 3
+100 Cos γ
-100 Sin γ
+.5747 α
-1 θ
+.5555 θ
+100 Cos α
-100 Sin α
-1 γ̇
-1 V̇
+100 Cos γ
+15x10⁻³ V̇ Sin γ
-15x10⁻³ V̇ Cos γ
+15x10⁻³ V̇
-15x10⁻³ V̇


PIN 76
DIGITAL
READOUT
2A
.01 ΔV
PHASE 2 & 3
.001 Z
231 R
55

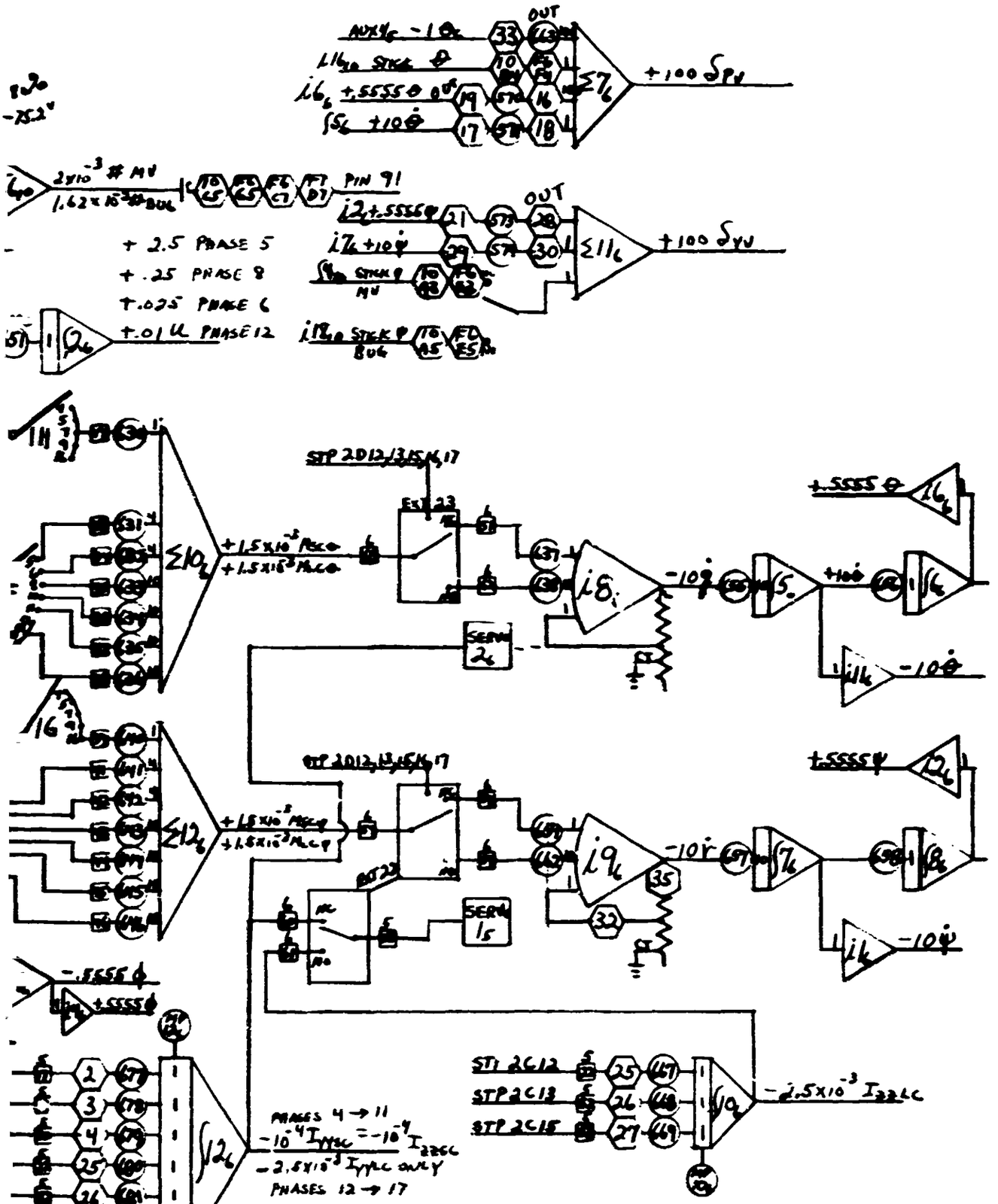
46 (PHASES 4 – 17)

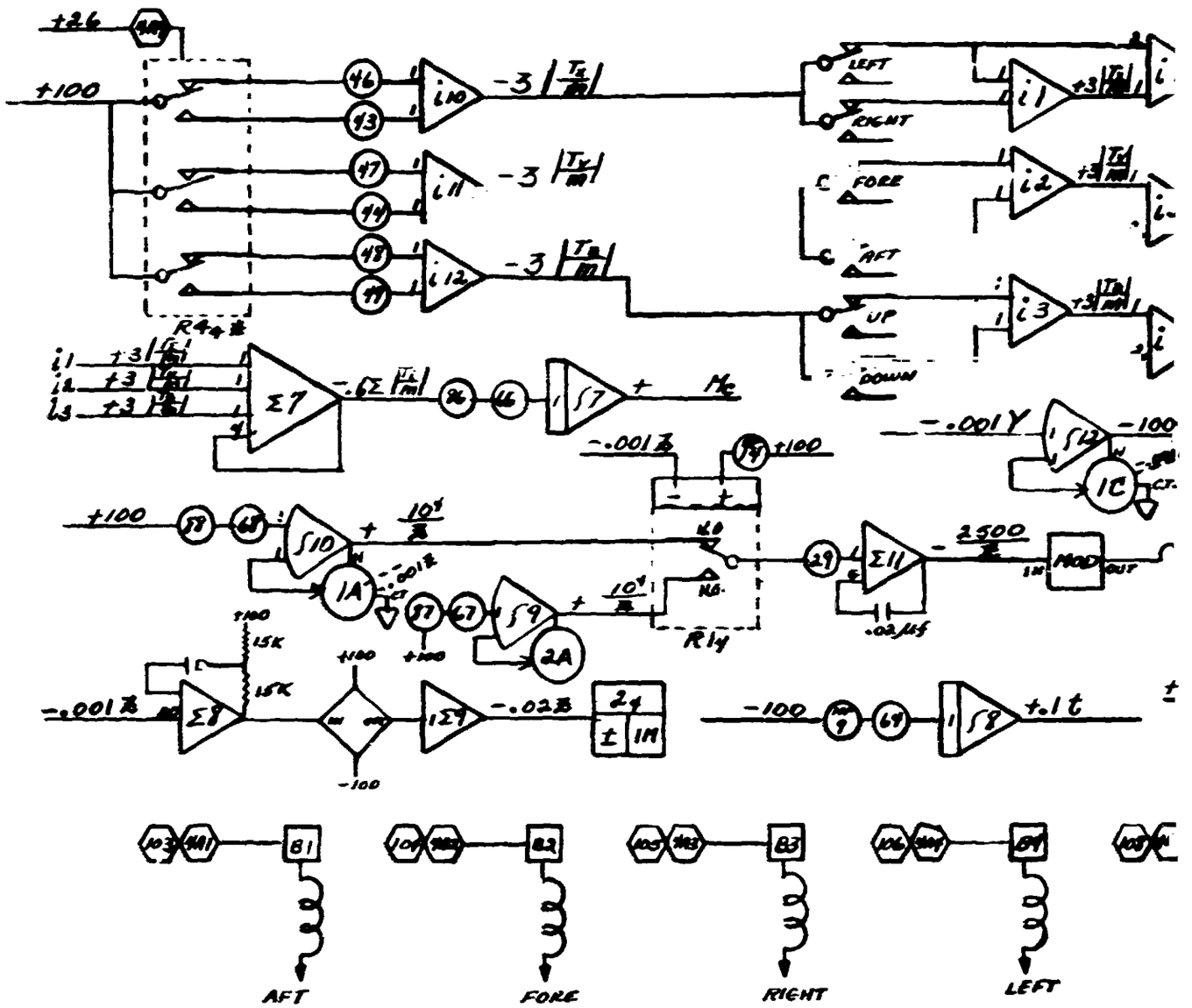


PROBLE:

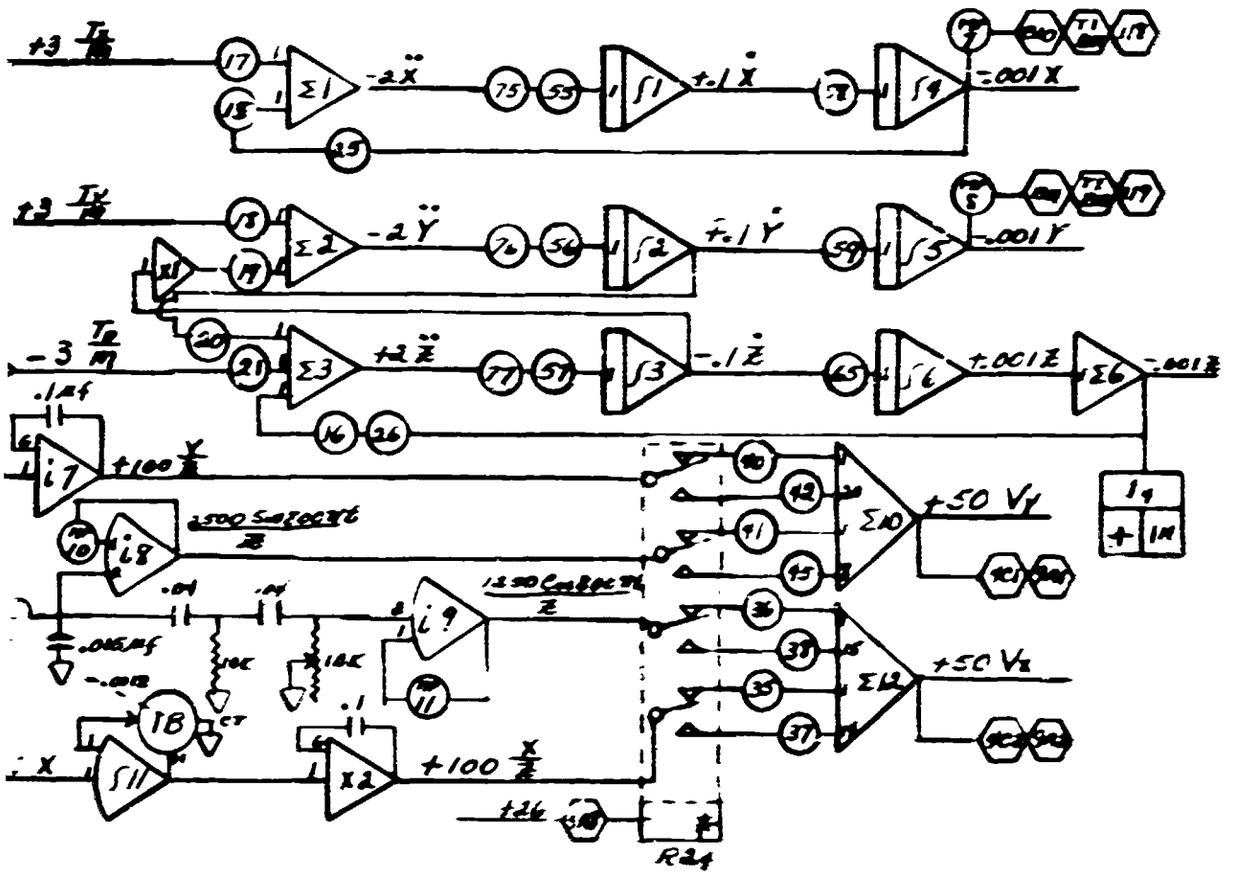

1A
1B
1C
1D
1E
1J
EXT 16
EXT 17
J-2 ENGINE
T3M
PHASES 4→11
PHASES 12→17
STP 2D12
STP 2D13
STP 2D15
STP 2D16
STP 2D17
-100'
+1'
-30°
-80°
-4X10⁻³
+10°
+.2 Msc BUS
+.02 Msc
Ext 21

46 (PHASES 4-17)

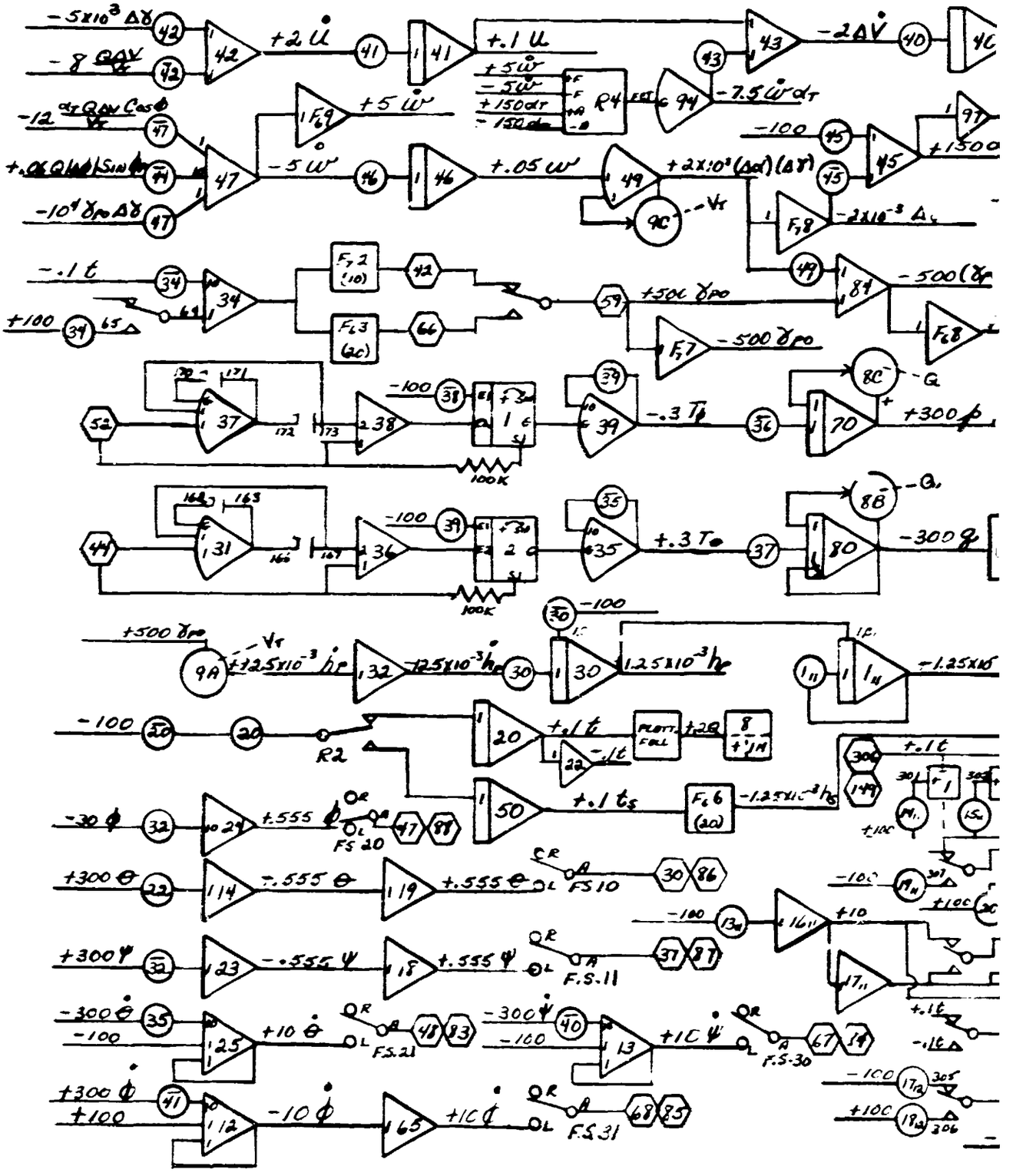



+100
LEFT
RIGHT
FORE
AFT
UP
DOWN
-.001Y
-100
+.1t
-.001Z
+100
2500
.02 μf
15K
-.02Z
Rly
AFT
FORE
RIGHT
LEFT

:ZVOUS


+3 Ix/m
Σ1
-2 Ẍ
∫1
+.1 Ẋ
∫4
-.001 X
+2 Iy/m
Σ2
-2 Ÿ
∫2
+.1 Ẏ
∫5
-.001 Y
-3 Iz/m
Σ3
+2 Z̈
∫3
-.1 Ż
∫6
+.001 Z
Σ6
-.001 Z
.1 mf
i7
+100 X/Z
i8
i9
.01
.01
.005 mf
10K
18K
.1
i11
18
CT
∫11
X2
+100 X/Z
+26
R24
Σ10
+50 VY
Σ12
+50 VZ
I4
+
IN
UP
DOWN

LMS PHAS


-5x10^3 Δγ
-8 QAV
+2 u̇
+.1 u
+5 ẇ
-5 ẇ
+150 dT
-150 dT
R4
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-2Δv̇
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+2x10^3 (Δα)(Δγ)
-Vr
-2x10^-3 Δα
-100
+1300
-.1 t
+100
+500 γpo
-500 γpo
-500 (γp
-100
-.3 Tp
+300 p
-Q
100K
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-300 q
-Q
-100
+500 γpo
-Vr
+125x10^-3 ḣp
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1.25x10^-3 hp
-1.25x10
-100
R2
+.1 t
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-1.25x10^-3 hs
-30 φ
+.555 φ
FS 20
+300 θ
-.555 θ
+.555 θ
FS 10
+300 ψ
-.555 ψ
+.555 ψ
F.S.11
-300 θ̇
-100
+10 θ̇
F.S.21
-300 ψ̇
-100
+10 ψ̇
F.S-30
+300 φ̇
+100
-10 φ̇
+10 φ̇
F.S.31
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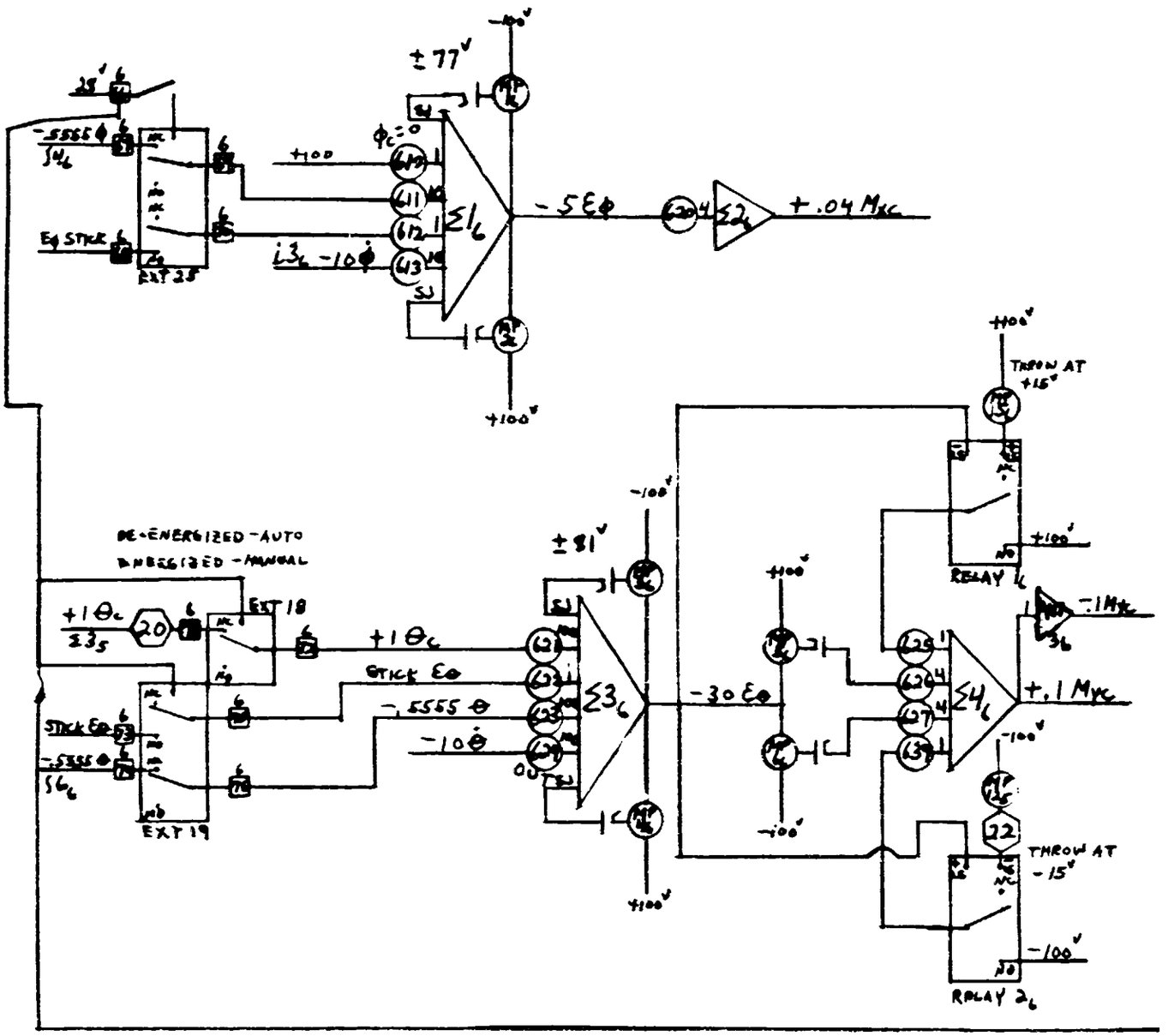
+10
+.1 t
-.1 t
+100
+100

PROBLEM 64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Eq STICK
EXT 25
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i3c -10φ
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Σ2c
+.04 Mxc
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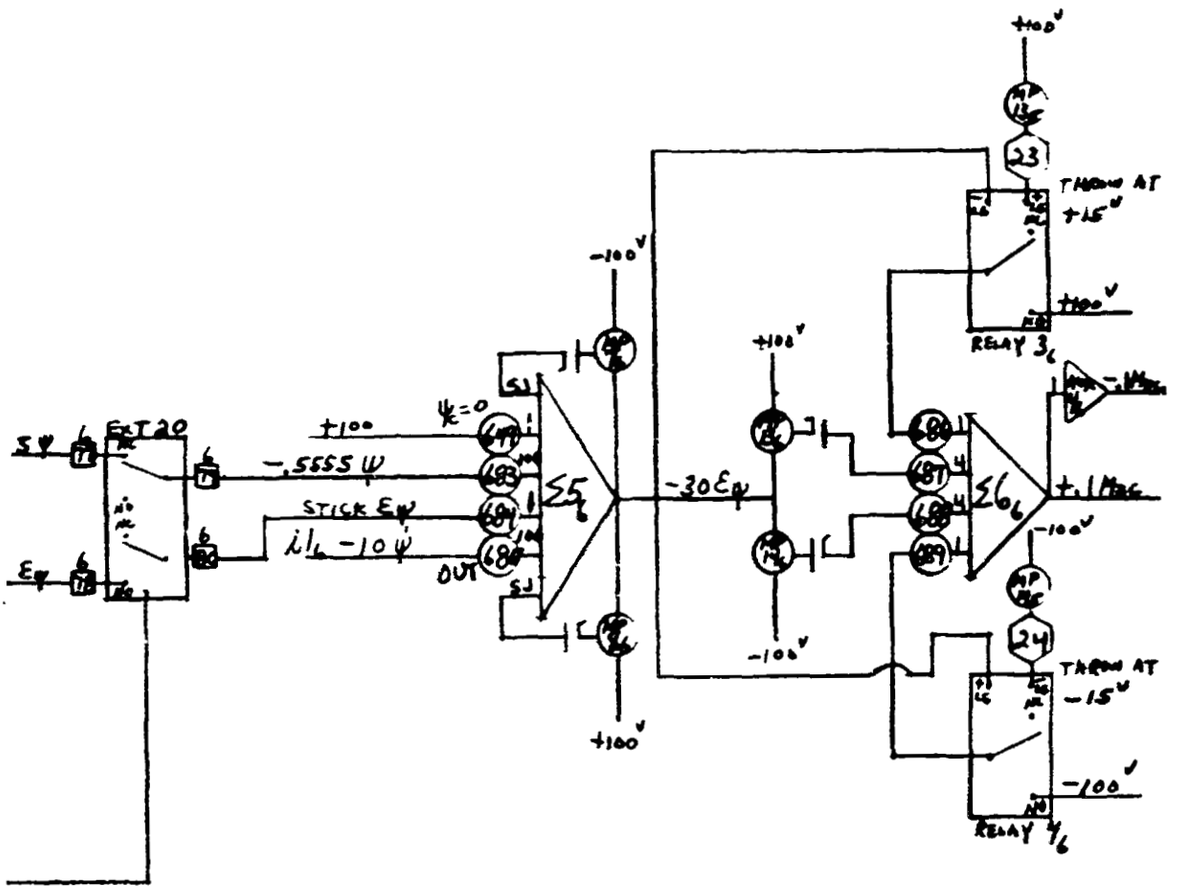
EXT 20
S_ψ
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$\psi_k = 0$
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STICK E_ψ
$\dot{\lambda} l_6$ -10 ψ
OUT
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-100V
+100V
-30 E_ψ
ΣS_6
+100V
-100V
+100V
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-100V
24
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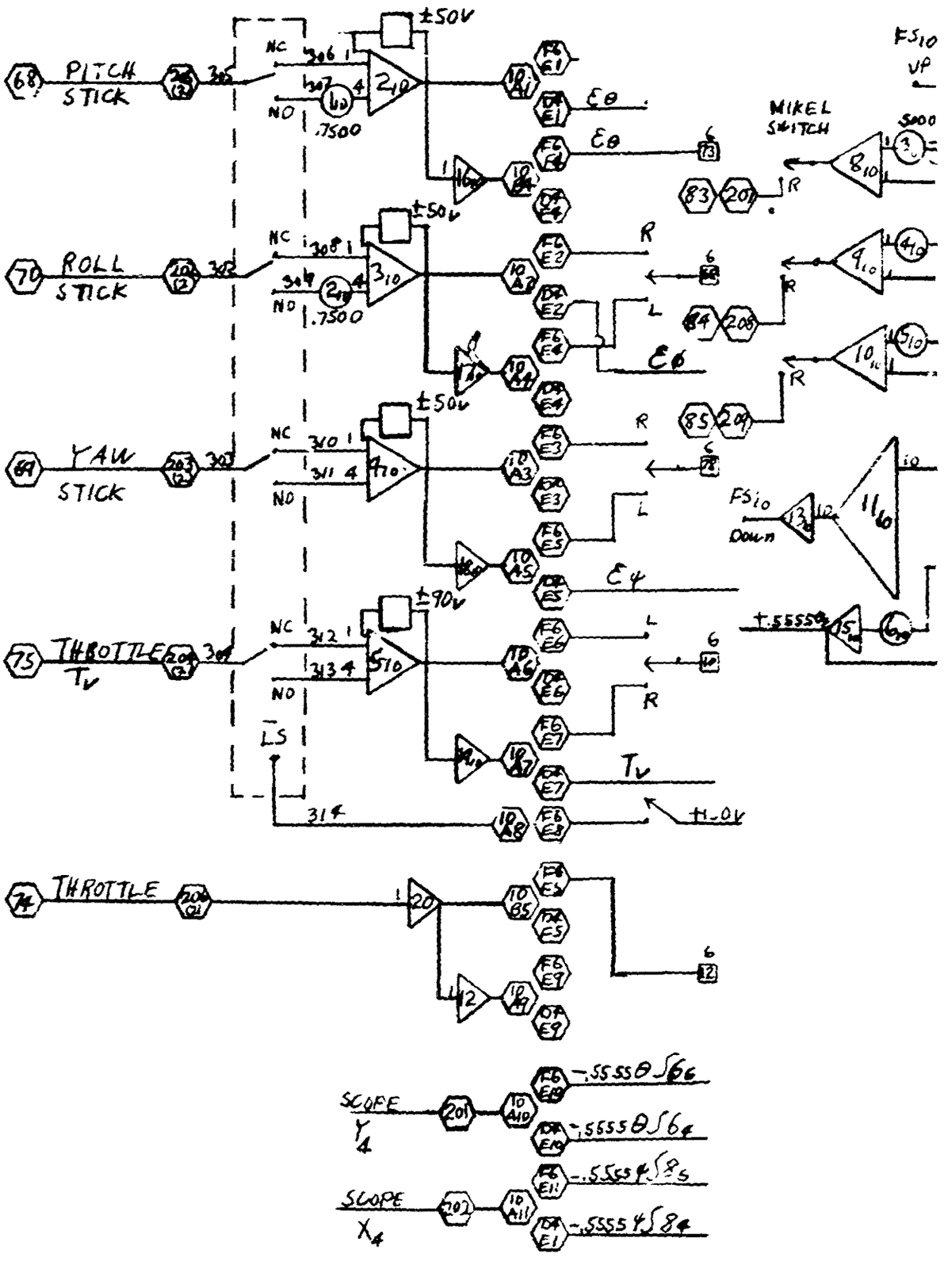
-100V
RELAY 4_6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ROLL STICK
YAW STICK
THROTTLE
T_V
THROTTLE
SCOPE
Y_4
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X_4
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FS_{10} UP
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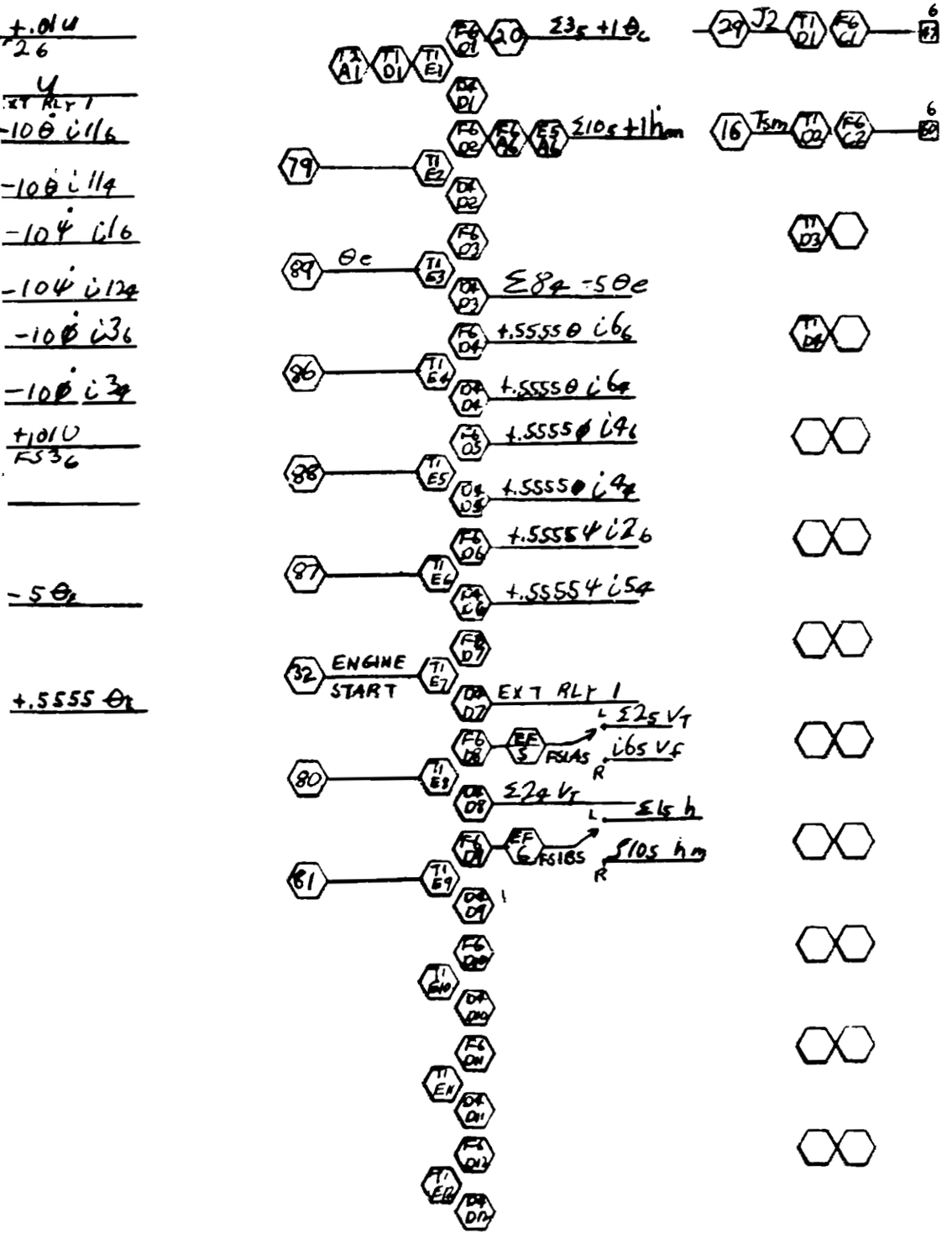
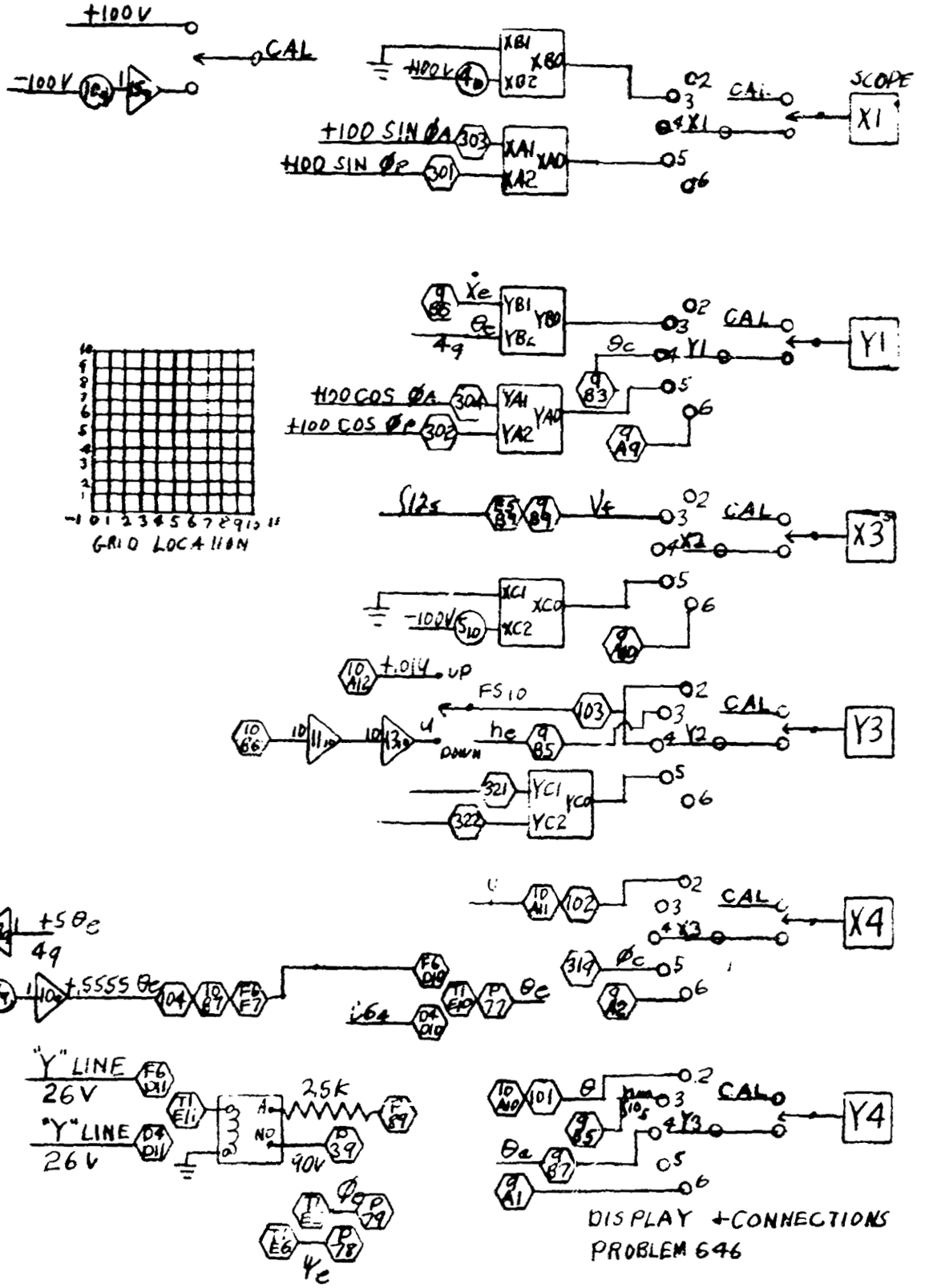


SIGNAL CONDITIONING
+INPUT-OUTPUT

PHASE	1	2+3	4-9	10+11	12+13	14	15-17	18-
INTERCONNECT PLUG 10A	—	CONNECT TO D4E	CONNECT TO F6E	→	→	—	CONNECT TO F6E	—
INTERCONNECT PLUG 10B	—	CONNECT TO D4F	CONNECT TO F6F	→	→	—	CONNECT TO F6F	—
INTERCONNECT PLUG T1E	DIS-CONNECT	CONNECT TO D4D	CONNECT TO F6D	→	→	—	CONNECT TO F6D	DIS-CONNECT
MIKEL SWITCH, MACH. 10	LEFT	RIGHT	→	→	→	—	RIGHT	LEFT
FS1 MACH. 5	—	—	LEFT	RIGHT	LEFT	—	LEFT	—
FS MACH. 10	—	UP	UP		UP			—
FS MACH 9 / FS 3 MACH. 6	—	UP	DOWN / LEFT					—
FS "X" MACH 9	4	2	→	3	4	6	2	5
FS "Y" MACH 9	1	2	→	3	4	6	2	5
SCOPE INPUT X1 VARIABLE	BLANK	→	→	ZERO BIAS	BLANK	BLANK	BLANK	SIN Θ / SIN Θe
X1 ZERO LOCATION	—	—	—	-1.5 / +1.5	—	—	—	5,5
X1 FULL SCALE VOLTAGE	—	—	—	N/A	→	→	→	+100V
X1 FULL SCALE LOCATION	—	—	—	N/A	→	→	→	10,5
Y1 VARIABLE	BLANK	→	→	Xe / Θe	BLANK	BLANK	BLANK	COS Θ / COS Θe
Y1 ZERO LOCATION	—	—	—	-1.5 / +1.5	—	—	—	5,5
Y1 FULL SCALE VOLTAGE	—	—	—	+100V	—	—	—	+100V
Y1 FULL SCALE LOCATION	—	—	—	-1,10 / +1,10	—	—	—	5,10
X3 VARIABLE	BLANK	ZERO	→	Vf	ZERO	BLANK	ZERO	ZERO BIAS
X3 ZERO LOCATION	—	0,0	→	0,0	0,0	—	0,0	0,5
X3 FULL SCALE VOLTAGE	—	N/A	→	+82.95	→	—	N/A	N/A
X3 FULL SCALE LOCATION	—	N/A	→	≈ 11,0	→	—	N/A	N/A
Y3 VARIABLE	BLANK	10&24	4	hm	4	BLANK	4	Re / he
Y3 ZERO LOCATION	—	0,0	→	0,0	0,0	—	0,0	10,5 / 0,5
Y3 FULL SCALE VOLTAGE	—	+100V	→	+53.75	+100V	—	+100V	+100V
Y3 FULL SCALE LOCATION	—	0,10	→	≈ 0,11	0,10	—	0,10	10,10 / 0,10
X4 VARIABLE	BLANK	Ψ	→	ZERO	ZERO	Vhe,	Ψ	Φe
X4 ZERO LOCATION	—	5,5	→	11,0	11,5	5,5	5,5	5,0
X4 FULL SCALE VOLTAGE	—	+20 V	→	N/A	→	+5Ω	+20V	+100
X4 FULL SCALE LOCATION	—	10,5	→	N/A	→	10,5	10,5	10,0
Y4 VARIABLE	BLANK	Θe	→	hm	Θa	Vhe,	Θe	ZERO
Y4 ZERO LOCATION	—	5,5	→	11,0	10,5	5,5	5,5	5,0
Y4 FULL SCALE VOLTAGE	—	+10 V	→	+2,5V	+15 V	+50V	+10 V	N/A
Y4 FULL SCALE LOCATION	—	5,10	→	11,10	11,10	5,10	5,10	N/A
FS4 MACH 6	—		RIGHT					
ALL 23 & 8 FS	LEFT	RIGHT	→	→	→	→	→	LEFT


+100V
CAL
-100V
XB1
XB0
XB2
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SCOPE
CAL
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+100 SIN ØA
303
XA1
XA0
+100 SIN Øe
301
XA2
Xe
YB1
YB0
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CAL
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YA0
+100 COS ØA
304
+100 COS Øe
302
YA2
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DISPLAY + CONNECTIONS
PROBLEM 646

APPENDIX F

Crew Diets for Each Flight

Crew Menu (1800 Calories) Flight I & II

5 June 1962 & 19 June 1962

Three Crew Members

First Day

Breakfast to be served outside of Simulator

B R E A K F A S T

	Quantity	Calories
Tomato Juice	6 Oz.	38
Eggs (2) Boiled	3 Oz.	150
Toast (1)	1 slice thin	50
Butterchip (1)	1/2 Oz.	50
Coffee or Tea (no cream or sugar)	Unlimited	-

L U N C H

Chicken Rice Soup (can)	8 Oz.	75
Saltines (2)	2	34
Swiss Steak	4 Oz.	260
String Beans	3/4 Cup	21
Bread	1 slice thin	50
Butterchip (1)	1/2 Oz.	50
Coffee or Tea (no cream or sugar)	Unlimited	-

D I N N E R

Grapefruit Cup	4 Oz.	50
Roast Pork (lean)	4 Oz.	350
Mashed Potatoes	4 Oz.	100
Peas	1/2 Cup	75
Cottage Cheese	3 Oz.	75
Bread	1 slice thin	50
Butterchip (1)	1/2 Oz.	50
Cantaloupe (1/2)	1/2	25
Coffee or Tea (no cream or sugar)	Unlimited	-

S N A C K

Sandwich:	Turkey	2 Oz.	
	Bread	2 Oz.	
	Butterchip	1/4 Oz.	
	Lettuce	--	235
Coffee			-
Total Calories			1788

REMARKS: Canned soup to be heated in Lacy Cup during flight.
Lunch will be packaged in compartment tray 7" x 9".
Dinner will be packaged in compartment tray and 3 (5") pattie pans.
Sandwich will be wrapped in aluminum foil.

6 June 1962 & 20 June 1962

Three Crew Members

Second Day

Food to be served inside of Simulator

B R E A K F A S T

	Quantity	Calories
Orange Juice	6 oz.	103
Egg Boiled	1 Med.	76
Ham	2 oz.	175
Bread - White	1 slice thin	50
Butterchip	1	50
Coffee or Tea (No cream or sugar)	unlimited	---

L U N C H

Pineapple Juice	4 oz.	50
Beef Stew	8 oz.	252
Cole Slaw	½ cup	104
Bread - White	1 slice thin	50
Butterchip	1	50
Fresh Apple	1	64
Coffee or Tea (no cream or sugar)	unlimited	----

D I N N E R

Grapefruit Juice	6 oz.	75
Veal Steak	4 oz.	175
Mashed Potatoes	½ cup	85
Buttered Mixed Vegetables	½ cup	30
Bread - white	1 slice thin	50
Butterchip	1	50
Pear Halves	2	75
Coffee or Tea (no cream or sugar)	unlimited	---

S N A C K

Cookies	5	125
Milk Skim	1 cup	88
Total Calories		1772

Remarks: All juices will be in cans. Lunch will be packaged in pattie pans (5"). Dinner will be packaged in compartment tray (7" x 9") and one pattie pan (5").

:7 June 1962 & 21 June 1962

Three Crew Members

Third Day

Food to be served inside of Simulator

B R E A K F A S T

	Quantity	Calories
Apricot Nectar	6 oz.	71
Eggs - Boiled or Poached	2	150
Bread	1 slice thin	50
Butterchip	1	50
Milk	1 cup	166

L U N C H

Roast Turkey	2 oz.	152
Buttered Noodles	½ cup	53
Buttered Lima Beans	¼ cup	38
Bread	1slice thin	50
Butterchip	1	50
Coffee or Tea (no cream or sugar)	unlimited	--

D I N N E R

Grape Juice	6 oz.	78
Roast Lamb	2½ oz.	163
Parsley Potatoes	1	100
Buttered Carrots	½ cup	25
Bread White	1 slice thin	50
Butterchip	1	50
Pear Halves	2	50
Coffee or Tea (no cream or sugar)	unlimited	---

S N A C K

Sandwich: Peanut Butter and Jelly - White Bread		270
Milk	1 Cup	166
Total Calories		1811

Remarks: Juices will be in cans. Lunch will be packaged in compartment tray (7" x 9"). Dinner will be packaged in compartment tray and pattie pan (5"). Sandwich will be wrapped in aluminum foil.

8 June 1962 & 22 June 1962

Three Crew Members

Fourth Day

Food to be served inside of Simulator

B R E A K F A S T

	Quantity	Calories
Stewed Prunes	4	121
Egg - Boiled or Poached	1	75
Bacon	2 slices	100
Bread White	1 slice thin	50
Butterchip	1	50
Milk	1 cup	166

L U N C H

Tomato Soup	½ cup	50
Tuna Casserole	1 cup	188
Asparagus	½ cup	12
Bread White	1 slice thin	50
Butterchip	1	50
Fig Bars	2	100
Coffee or Tea (no cream or sugar)	unlimited	--

S N A C K

Sandwich: Egg Salad and Lettuce - Rye Bread	347
Coffee	--
Total Calories	1059

Remarks: Fruit will be put in 5" pattie pan. Canned soup to be heated in Lacy Cup during flight. Lunch will be packaged in 2 (5") pattie pans. Juice will be in a can.

Dinner served outside the simulator.

Crew Menu (1800 Calories) Flight I & II

5 June 1962 & 19 June 1962

Three Crew Members

First Day

Breakfast to be served outside of Simulator

BREAKFAST

	Quantity	Calories
Tomato Juice	6 oz.	38
Eggs (2) Boiled	3 oz.	150
Toast (1)	1 slice thin	50
Butterchip (1)	½ oz.	50
Coffee or Tea (no cream or sugar)	unlimited	--

LUNCH

Chicken Rice Soup (can)	8 oz.	75
Saltines (2)	2	34
Swiss Steak	4 oz.	260
String Beans	3/4 cup	21
Bread	1 slice thin	50
Butterchip (1)	½ oz.	50
Coffee or Tea (no cream or sugar)	unlimited	--

DINNER

Grapefruit Cup	4 oz.	50
Roast Port (lean	4 oz.	350
Mashed Potatoes	4 oz.	100
Peas	½ cup	75
Cottage Cheese	3 oz.	75
Bread	1 slice thin	50
Butterchip (1)	½ oz.	50
Cantaloupe (½)	½	25
Coffee or Tea (no cream or sugar)	unlimited	--

SNACK

Sandwich:	Turkey	2 oz.	
	Bread	2 oz.	
	Butterchip	¼ oz.	235
	Lettuce	---	--
Coffee			
Total Calories			1788

Remarks: Canned soup to be heated in Lacy Cup during flight
Lunch will be packaged in compartment tray 7" x 9"
Dinner will be packaged in compartment tray and 3 (5") pattie pans.
Sandwich will be wrapped in aluminum foil

Crew Menu (1500 Calories) Flight III

6 July 1962

Three Crew Members

First Day

Food to be served inside of Simulator

B R E A K F A S T

(Outside of Simulator)

	Quantity	Calories
Egg - Boiled or Poached	1	75
Bacon	2 slices	100
Bread White	1 thin slice	50
Butter	1 pat	50
Milk	1 cup	166

L U N C H

Tomato Soup	½ cup	50
Tuna Casserole	1 cup	188
Asparagus	½ cup	12
Bread White	1 thin slice	50
Butter	1 pat	50
Coffee or Tea (no cream or sugar)	unlimited	--

D I N N E R

Apple Juice	6 ozs.	75
Filet of Sole	3 ozs.	63
Baked Potato	1 small	97
Buttered Peas	½ cup	50
Bread Rye	1 thin slice	50
Butter	1 pat	50
Cherry Jello and Cream	½ cup	85
Coffee or Tea (no cream or sugar)	unlimited	--

S N A C K

Sandwich: Ham lean and lettuce - Rye Bread	275
Coffee	--

Total Calories	1536

Remarks: Fruit will be put in 5" pattie pan. Canned soup to be heated in Lacy Cup during flight. Lunch will be packed in compartment pans 7" x 9" and pattie pan 5". Sandwich will be wrapped in aluminum foil. Egg or Eggs to be cooked in Lacy Cup.

Crew Menu (1500 Calories) Flight III

7 July 1962

Three Crew Members

Second Day

Food to be served inside of Simulator

B R E A K F A S T

	Quantity	Calories
Orange Juice	6 oz.	103
Egg - Boiled	1 med.	76
Ham	2 oz.	175
Bread - White	1 slice thin	50
Butterchip	1	50
Coffee or Tea (no cream or sugar)	unlimited	--

L U N C H

Pineapple Juice	4 oz.	50
Beef Stew	8 oz.	252
Bread White	1 slice thin	50
Butterchip	1	50
Fresh Apple	1	64
Coffee or Tea (no cream or sugar)	unlimited	--

D I N N E R

Grapefruit Juice	6 oz.	75
Veal Steak	4 oz.	170
Buttered Mixed Vegetables	½ cup	30
Bread White	1 slice thin	50
Butterchip	1	50
Coffee or Tea (no cream or sugar)	unlimited	--

S N A C K

Cookies	5	125
Milk Skim	1 cup	83
Total Calories		1508

Remarks: All juices will be in cans. Lunch will be packaged in pattie pans (5"). Dinner will be packaged in compartment tray (7" x 9") and one pattie pan (5").

Crew Menu (1500 Calories) Flight III

8 July 1962

Three Crew Members

Third Day

Food to be served inside of Simulator

B R E A K F A S T

	Quantity	Calories
Apricot Nectar	6 oz.	71
Egg - Boiled or Poached	1 med.	75
Bread	1 slice thin	50
Butterchip	1	50
Milk	1 cup	166

L U N C H

Roast Turkey	2 oz.	152
Apple Sauce	½ cup	50
Buttered Lima Beans	½ cup	38
Bread	1 slice thin	50
Butterchip	1	50
Coffee or Tea (no cream or sugar)	unlimited	--

D I N N E R

Tomato Juice	4 oz.	25
Roast Lamb	2 oz.	130
Parsley Potatoes	1	100
Buttered Carrots	½ cup	25
Bread White	1 slice thin	50
Butterchip	1	50
Coffee or Tea (no cream or sugar)	unlimited	--

S N A C K

Sandwich #: Peanut Butter Cookies	2	200
Milk	1 cup	166
Total Calories		1498

Remarks: Juices will be in cans. Lunch will be packaged in compartment tray (7" x 9"). Dinner will be packaged in compartment tray and pattie pan (5"). Sandwich will be wrapped in aluminum foil.

Crew Menu (1500 Calories) Flight II

9 July 1962

Three Crew Members

Fourth Day

Food to be served inside of Simulator

B R E A K F A S T

	Quantity	Calories
Tomato Juice	6 oz.	38
Egg - Boiled	1 Med.	75
Toast	1 slice thin	50
Butterchip (1)	½ oz.	50
Coffee or Tea (no cream or sugar)	unlimited	--

L U N C H

Chicken Rice Soup (can)	8 oz.	75
Saltines (2)	2	34
Swiss Steak		200
String Beans	3/4 cup	21
Bread	1 slice thin	50
Butterchip (1)	½ oz.	50
Coffee or Tea (no cream or sugar)	unlimited	--

D I N N E R

Grapefruit Cup	4 oz.	50
Roast Pork (lean)	2 oz.	200
Masked Potatoes	4 oz.	100
Peas	½ cup	75
Cottage Cheese	3 oz.	75
Bread	1 slice thin	50
Butterchip (1)	½ oz.	50
Cantaloupe (½)	½	25
Coffee or Tea (no cream or sugar)	unlimited	--

S N A C K

Sandwich:	Turkey	2 oz.	
	Bread	2 oz.	
	Butterchip	½ oz.	
	Lettuce	--	235
Coffee			--
Total Calories			1503

Remarks: Canned soup to be heated in Lacy Cup during flight. Lunch will be packaged in compartment tray 7" x 9". Dinner will be packaged in compartment tray and 3 (5") pattie pans. Sandwich will be wrapped in aluminum foil.

Crew Menu (1500 Calories) Flight III

10 July 1962

Three Crew Members

Fifth Day.

Food to be served inside of Simulator

B R E A K F A S T

	Quantity	Calories
Orange Juice	6 oz.	103
Egg - Boiled	1 Med.	75
Toast	1 thin slice	59
Butterchip (1)	½ oz.	50
Coffee or Tea (no cream or sugar)	unlimited	--

L U N C H

Tomato Juice	6 oz.	38
Beef and Noodles	1 cup	253
Buttered Beets	¼ cup	37
Bread	1 thin slice	50
Pineapple Slice	1 slice	95
Coffee or Tea (no cream or sugar)	unlimited	--

D I N N E R

Apple Juice	½ cup	124
Baked Ham	2 oz.	226
Buttered Succotash	¼ cup	36
Steamed Rice	½ cup	100
Coffee or Tea (no cream or sugar)	unlimited	--

S N A C K

Sandwich: Chicken Salad on thin white bread	250
Coffee	--
Total Calories	1537

Remarks: All juices will be in cans. Egg to be cooked in Lacy Cup. Lunch and Dinner will be packaged in compartment trays 7" x 9". Sandwich will be wrapped in aluminum foil.

Crew Menu (1500 Calories) Flight III

11 July 1962

Three Crew Members

Sixth Day

Food to be served inside of Simulator

B R E A K F A S T

	Quantity	Calories
Grapefruit Sections	½ cup	50
Scrambled Egg	1 med.	75
Coffee Cake	1 piece	106
Coffee or Tea (no cream or sugar)	unlimited	--

L U N C H

Roast Chicken Breast	8 oz.	210
Buttered Carrots	½ cup	11
Masked Potatoes	½ cup	100
Bread	1 thin slice	50
Butter	½ oz.	50
Coffee or Tea (no cream or sugar)	unlimited	--

D I N N E R

Cantaloupe	½	25
Hamburger	1 - 3 oz.	195
Spinach	½ cup	13
Potato Baked	1 Med.	85
Bread	1 thin slice	50
Butter	½ oz.	50
Pear Halves	2	80
Coffee or Tea (no cream or sugar)	unlimited	--

S N A C K

Sandwich - Tuna Salad		350
Coffee or Tea (no cream or sugar)	unlimited	--
Total Calories		1500

Remarks: Fruit will be put in 5" pattie pans. Lunch and Dinner will be packaged in compartment trays 7" x 9". Sandwich will be wrapped in aluminum foil.

Crew Menu (1500 Calories) Flight III

12 July 1962

Three Crew Members

Seventh Day

Food to be served inside of Simulator

B R E A K F A S T

	Quantity	Calories
Tomato Juice	6 oz.	38
Egg - Soft Boiled	1 Med.	75
Ham	2 oz.	226
Bread, White	1 thin slice	64
Butter	½ oz.	50
Milk	1 cup	166

L U N C H

Grape Juice	½ cup	75
Spaghetti & Meat Sauce		
Spaghetti	½ cup	109
Meat Sauce	½ cup	135
Cole Slaw	½ cup	104
Buttered Wax Beans	¼ cup	14
Coffee or Tea (no cream or sugar)	unlimited	--

D I N N E R

Grapefruit Juice	1 cup	50
Roast Turkey	2 oz.	152
Buttered Noddles	½ cup	53
Buttered Peas	¼ cup	28
Bread	1 thin slice	50
Butter	½ oz.	50
Coffee or Tea (no cream or sugar)	unlimited	--

S N A C K

Sugar Cookies	3	66
Coffee or Tea (no cream or sugar)	unlimited	--
Total Calories		1505

Remarks: All Juices will be in cans. Egg to be cooked in Lacy Cup. Lunch and Dinner will be packaged in compartment trays 7" x 9" and 5" pattie pan.

VIII. References

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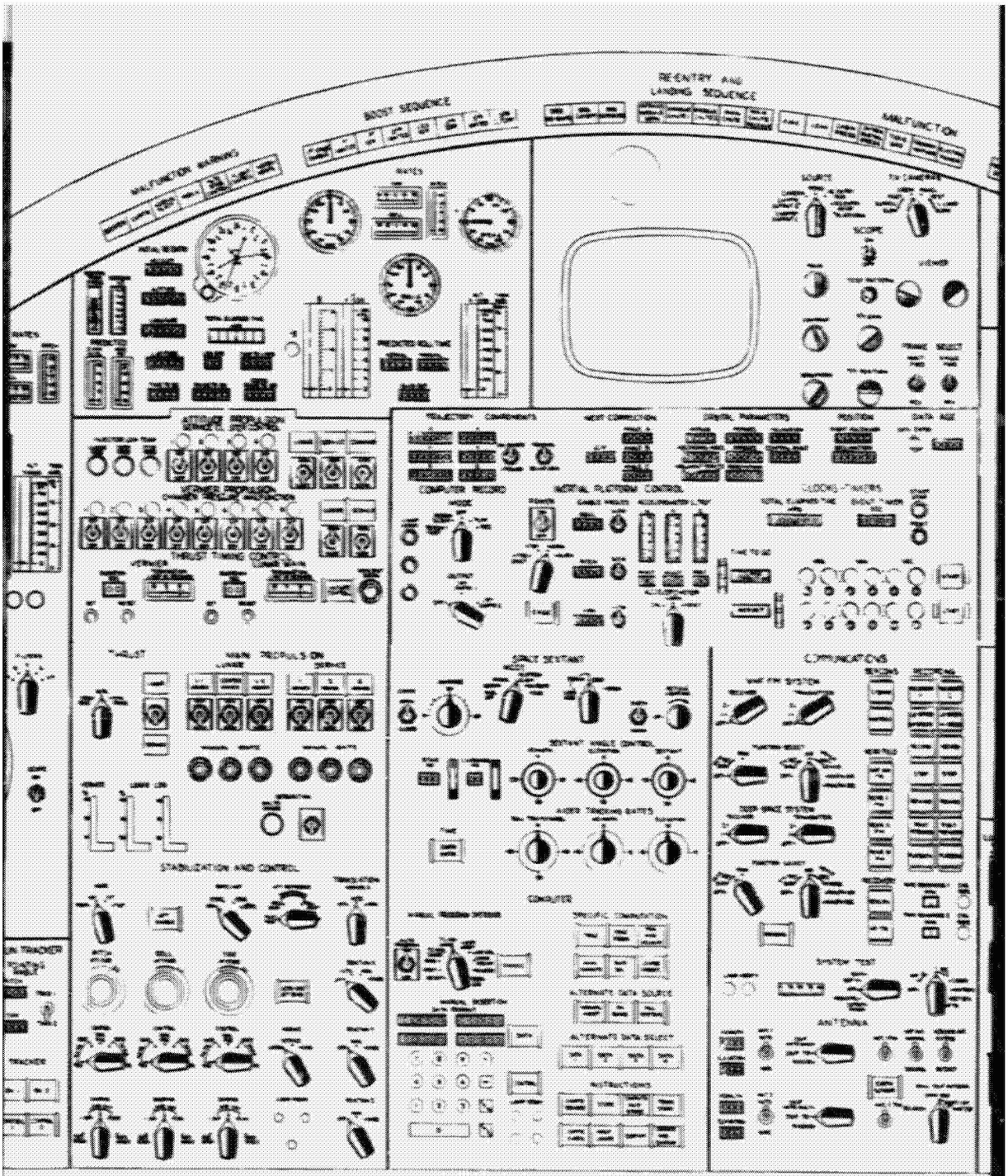
IX. Illustrations

Fig. 1. External View of Main Vehicle Simulator

Fig. 2. Tunnel Connection Between Main Simulator and Excursion Vehicle

Fig. 3. Main Simulator Flight Deck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RE-ENTRY AND LANDING SEQUENCE
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MALFUNCTION WARNING
RATES
TRAJECTORY COMPARATOR
MISSILE POSITION CONTROL
COMPUTER RECORD
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STABILIZATION AND CONTROL
COMMUNICATIONS
COMPUTER
ALTERNATE DATA SOURCE
ALTERNATE DATA SELECT
INSTRUCTIONS
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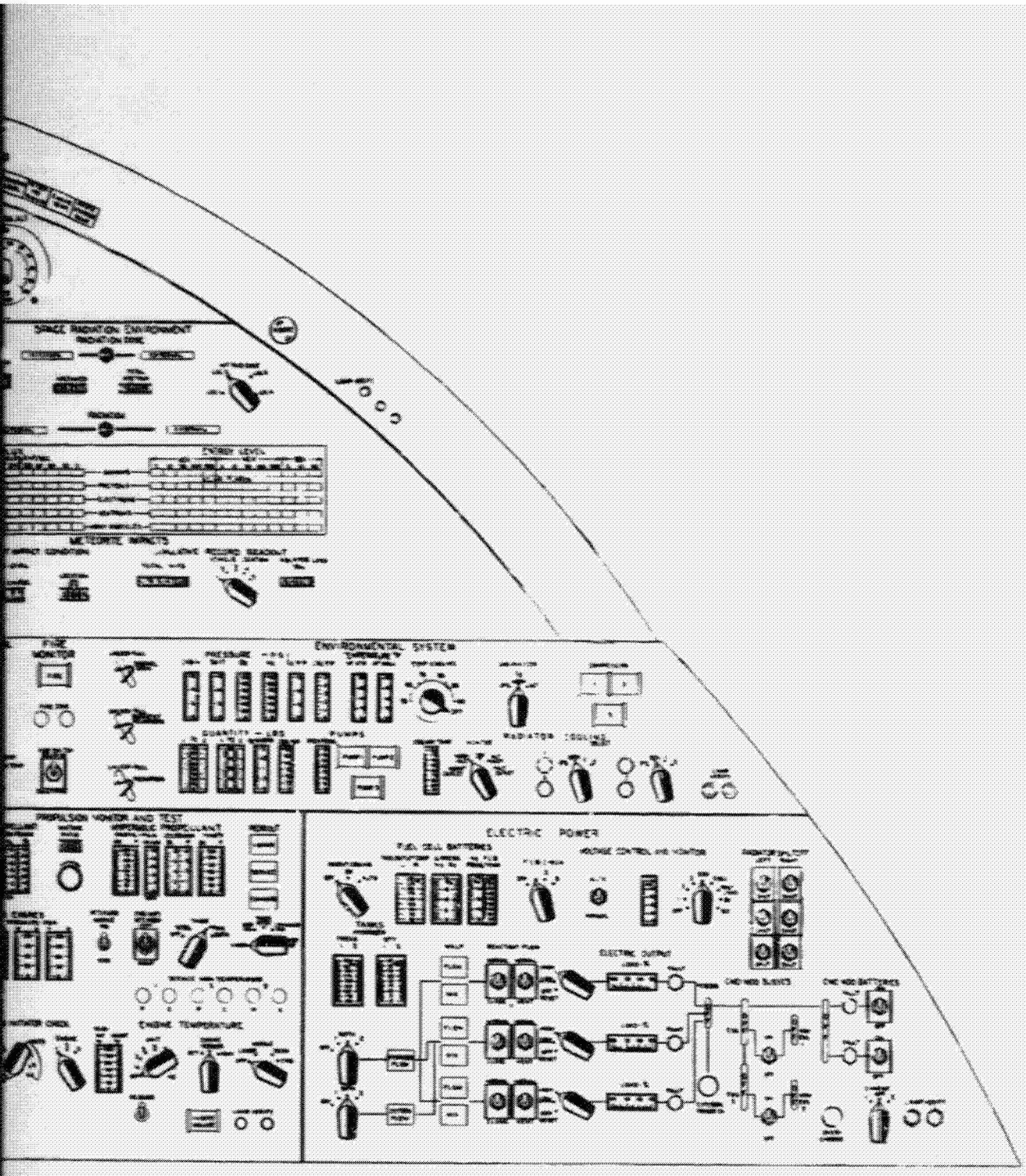


Fig. 4. Main Simulator Display Panel

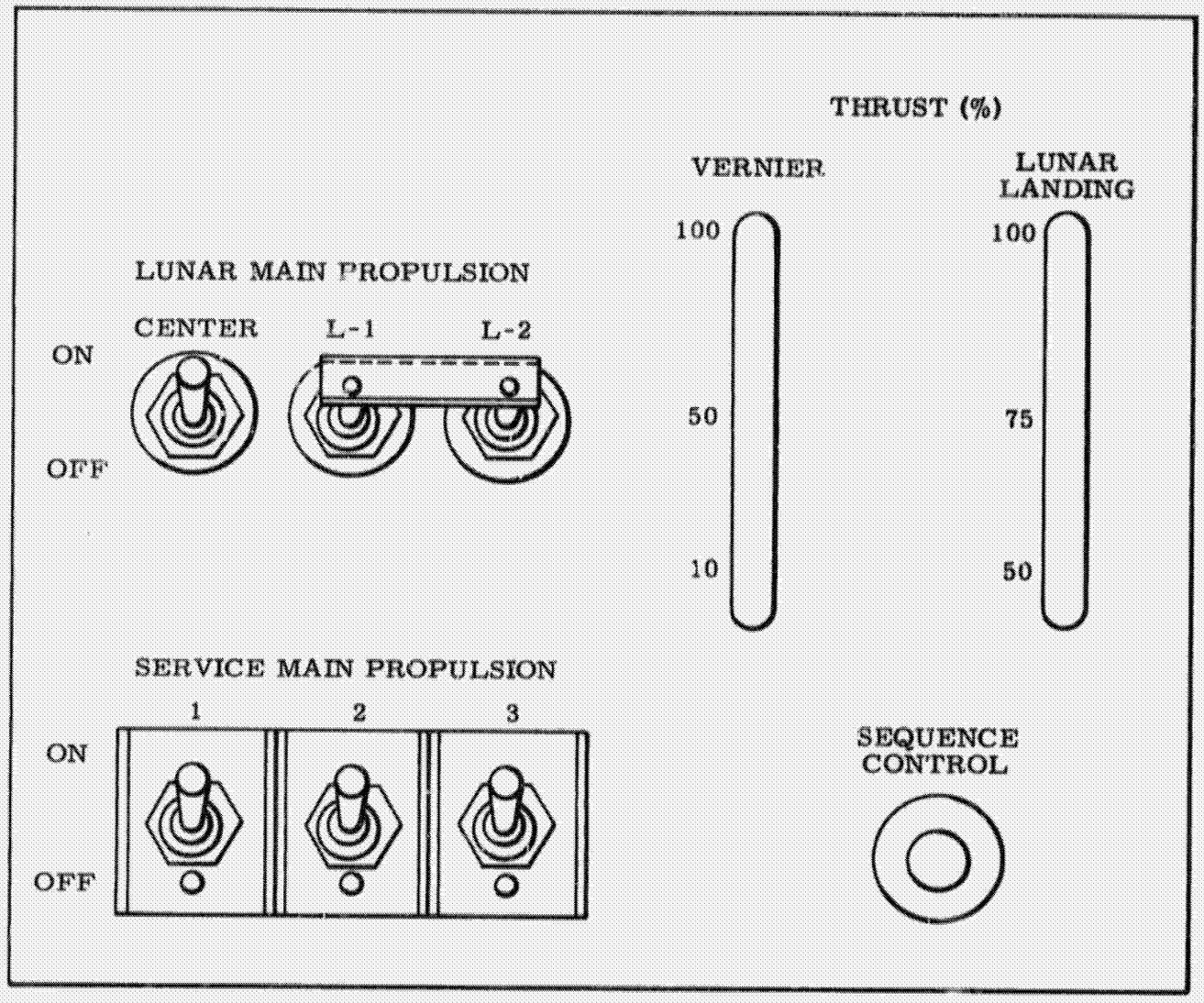


Fig. 4A. Throttle Box

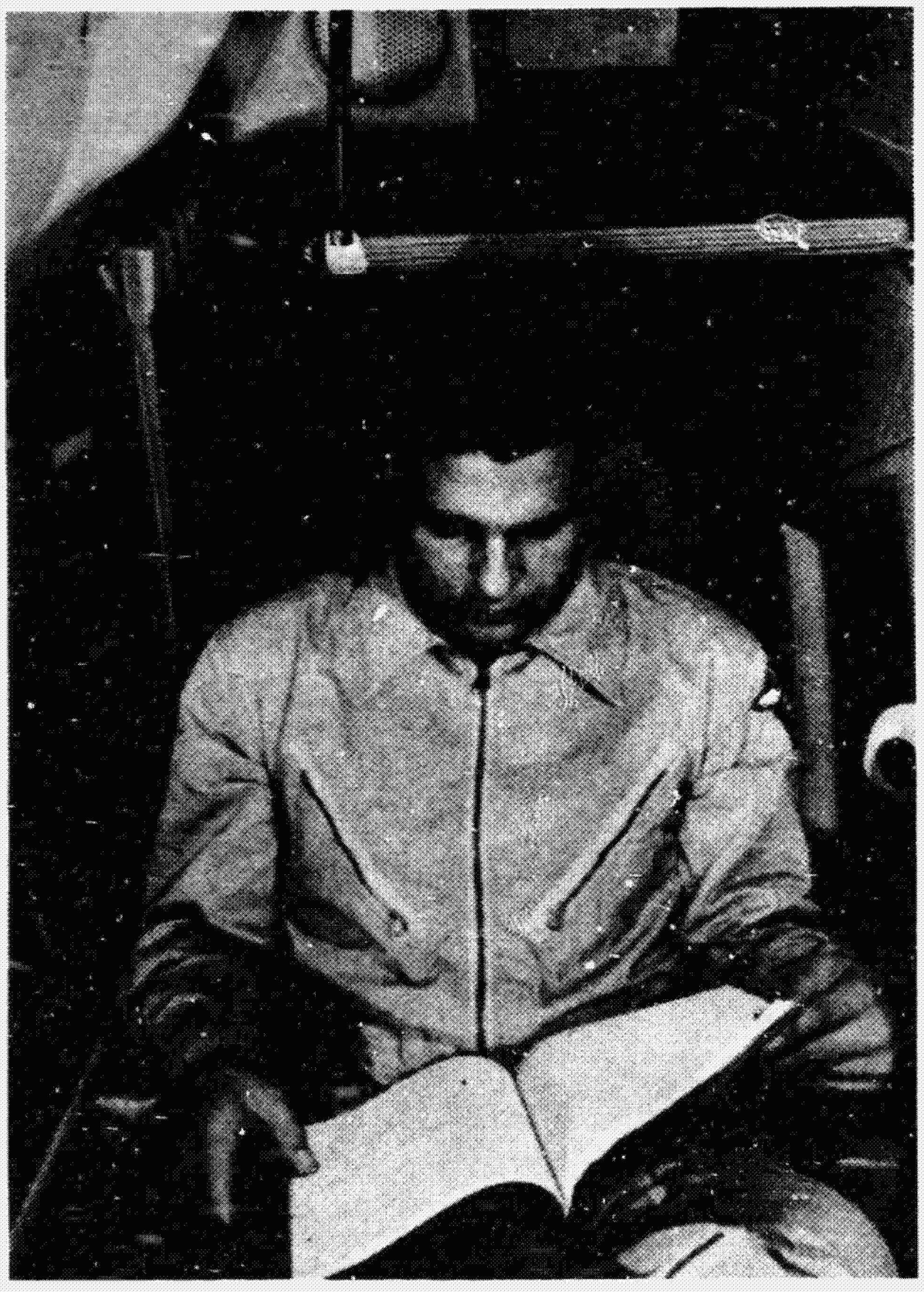


Fig. 5. Main Simulator Off-Duty Area

Fig. 6. Excursion Vehicle--External View

Fig. 7. Rendezvous Projection Tower

Fig. 8. Excursion Vehicle Display Panel

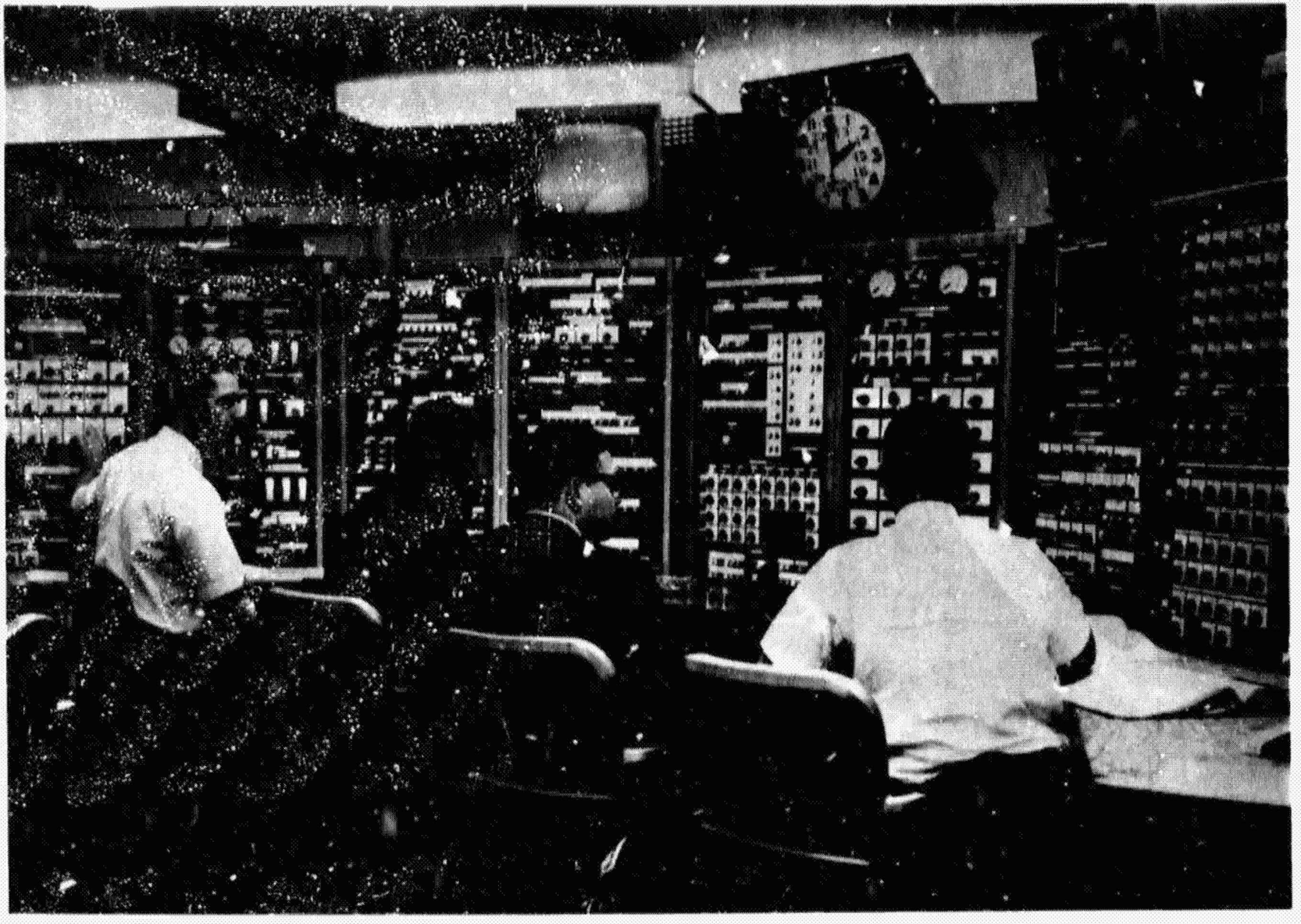
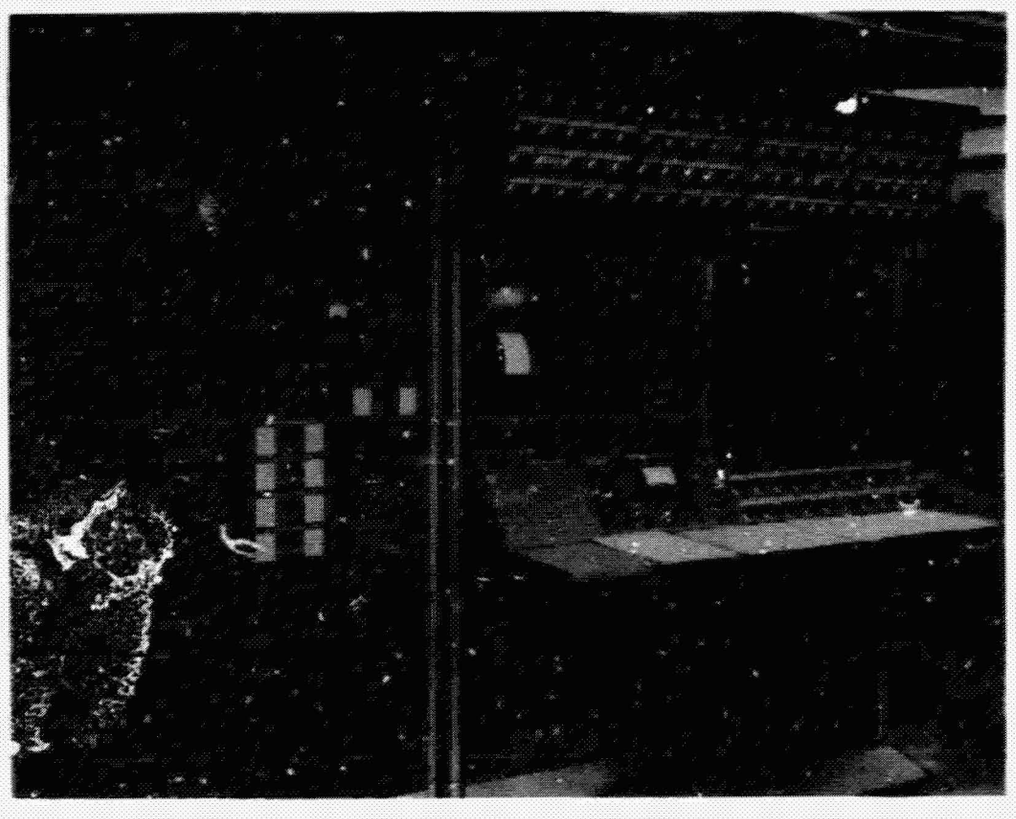


Fig. 9. Simulator Control Room



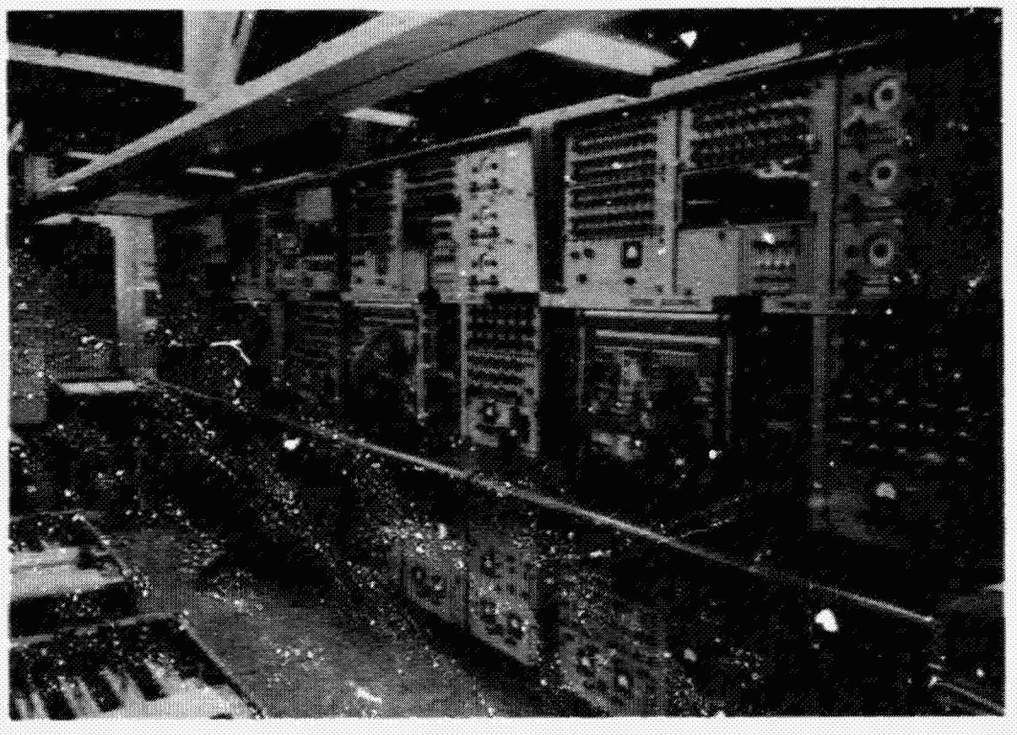


Fig. 10. Analog Computer Facilities

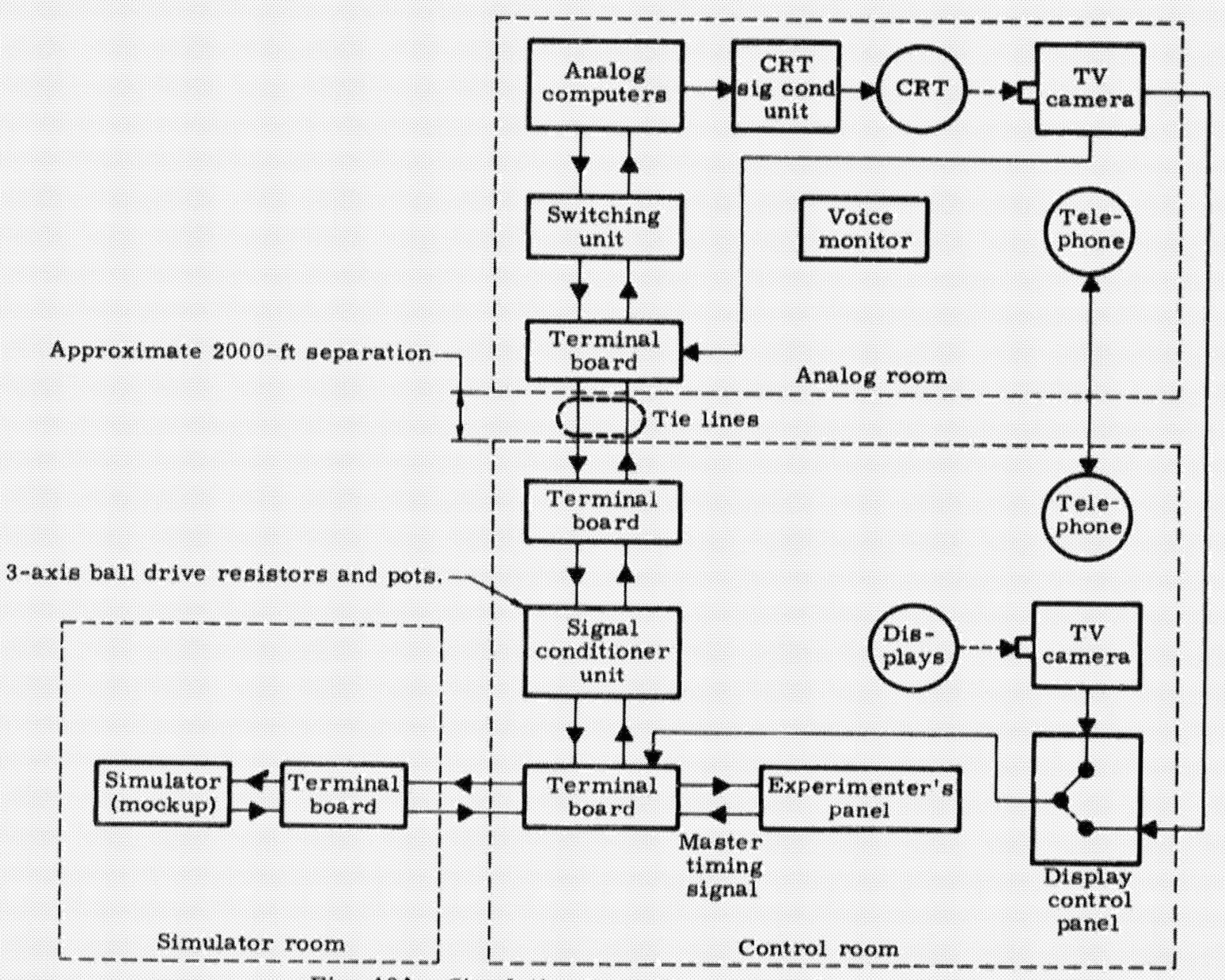


Fig. 10A. Simulation Data Flow Schematic

Fig. 11. In-Flight Exerciser

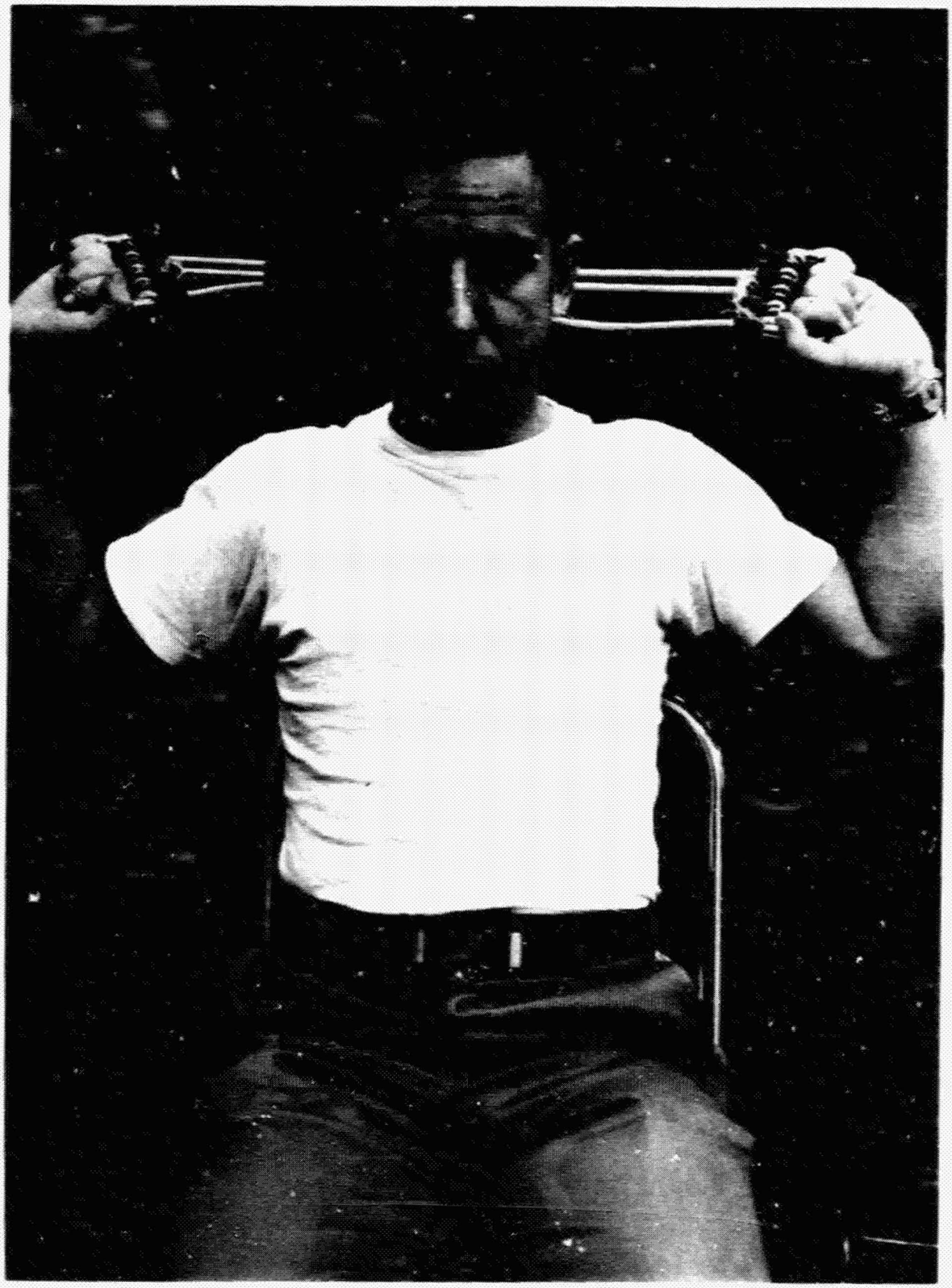


Fig. 12. Arm Abduction Exercise

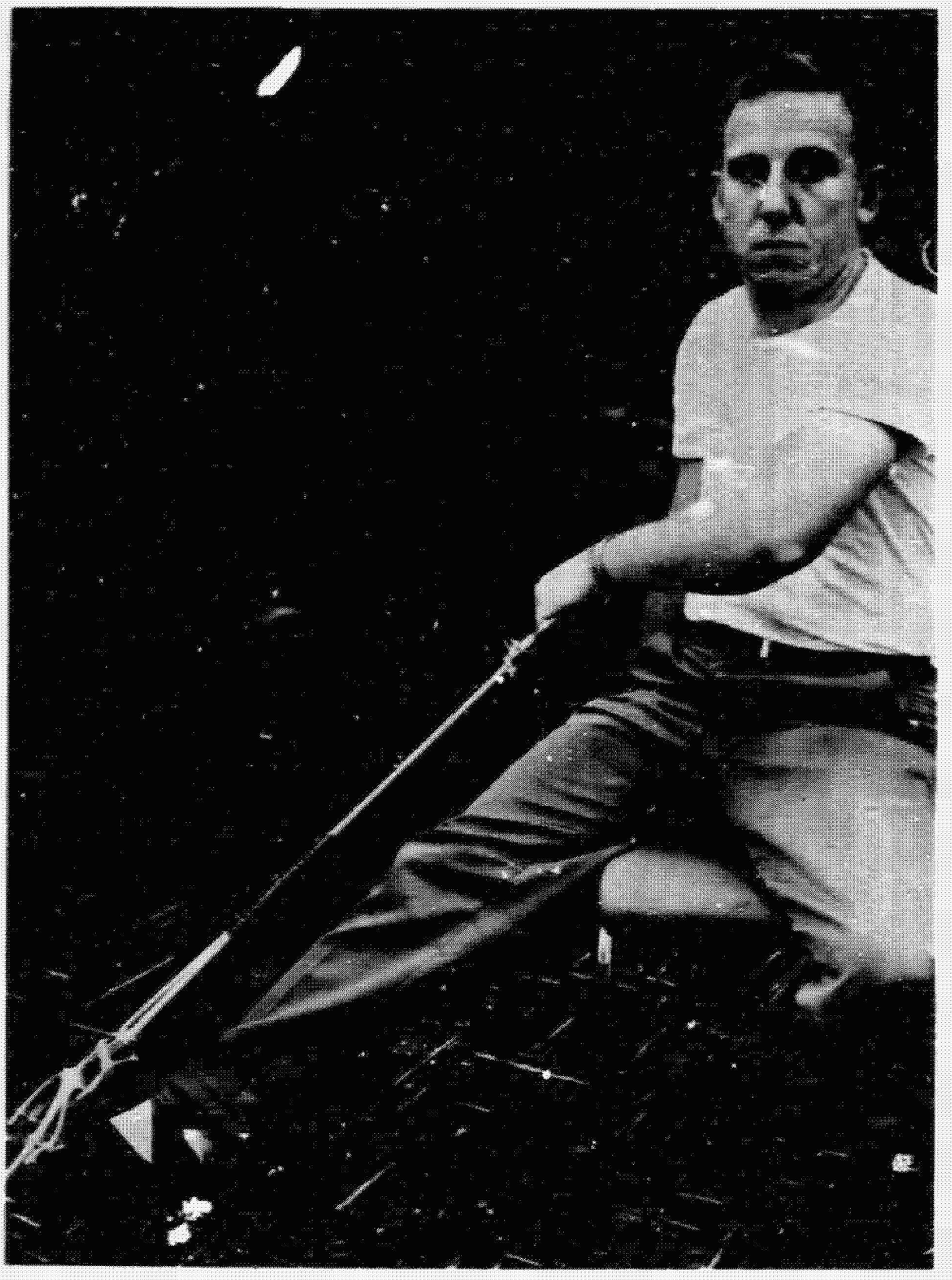


Fig. 13. Leg Abduction Exercise

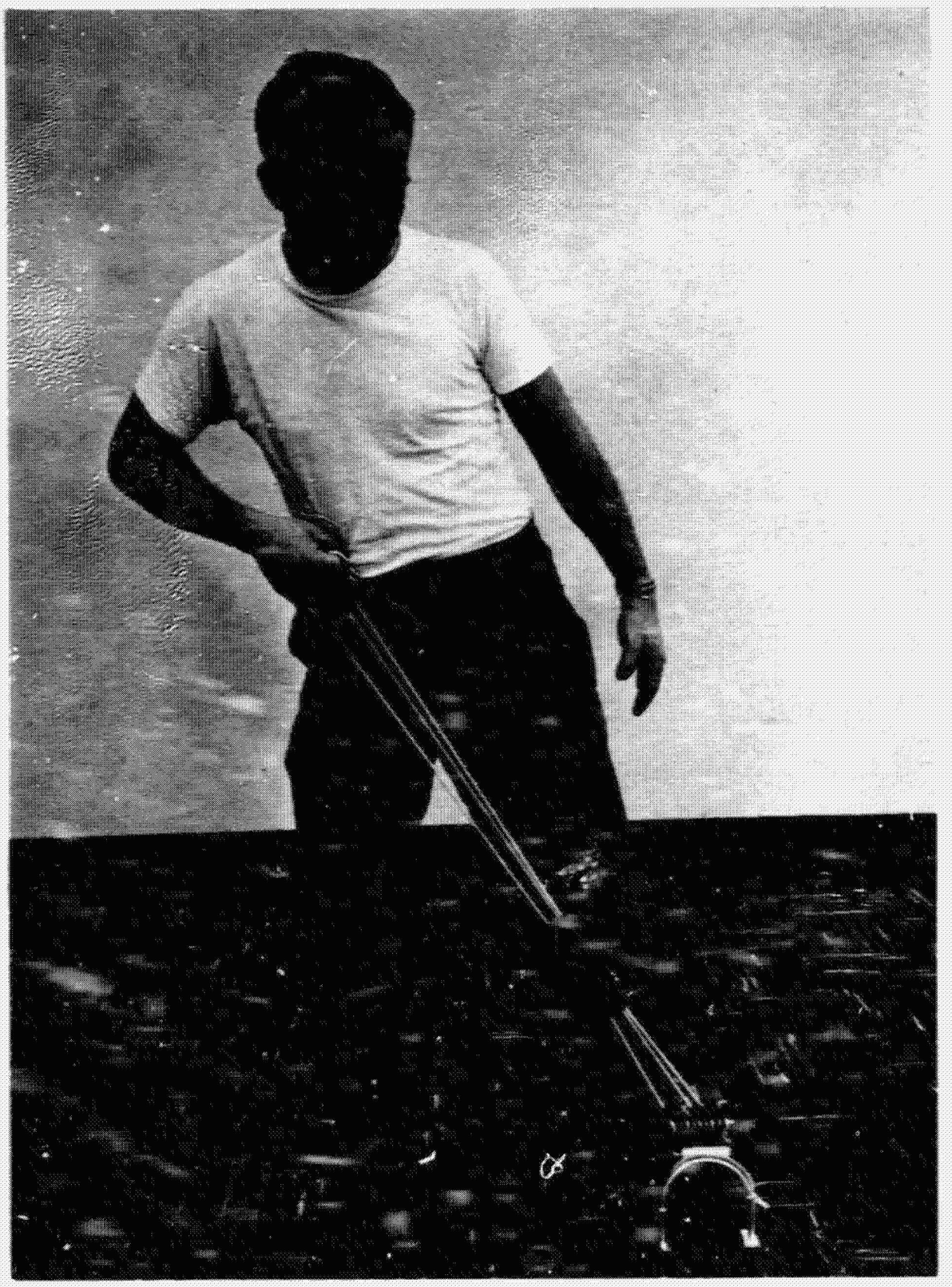


Fig. 14. Side Bending Exercise

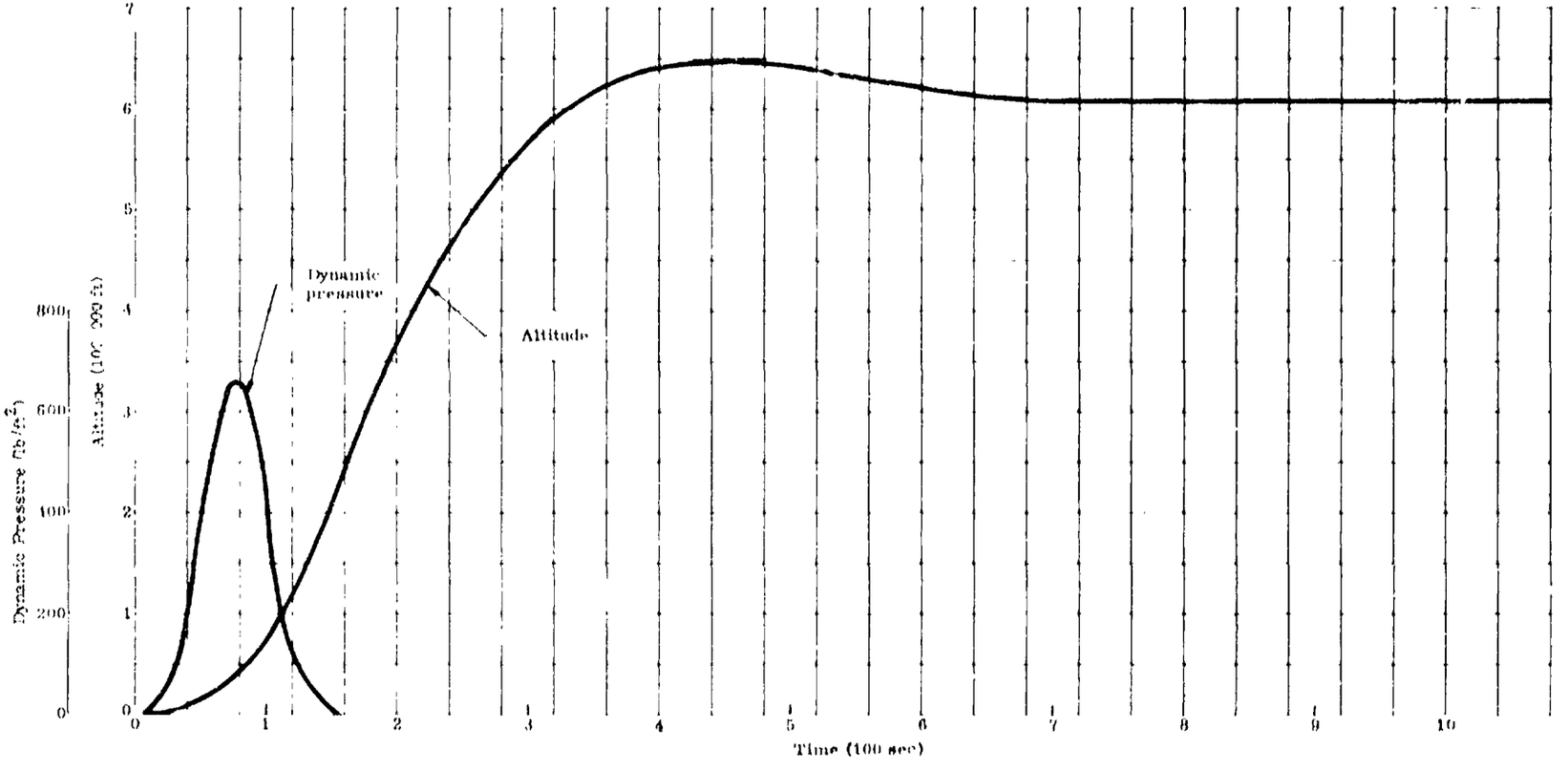


Fig. 15. Altitude and Dynamic Pressure Versus Time--Earth Ascent

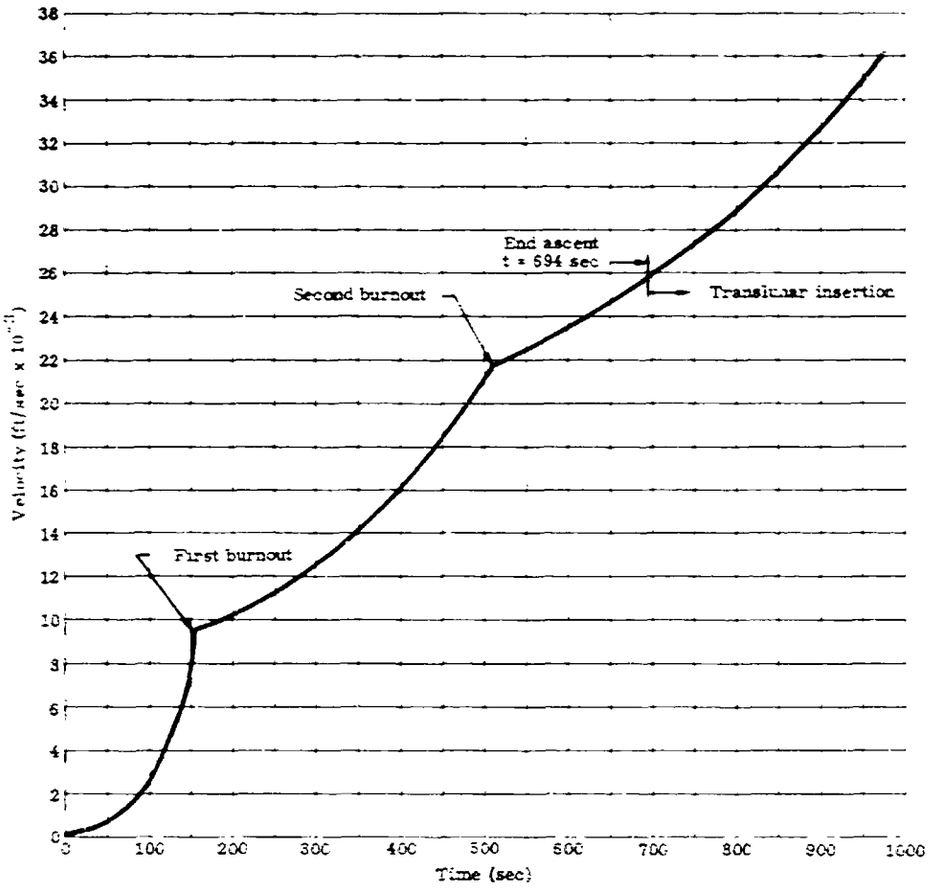


Fig. 16. Total Velocity Versus Burning Time--Earth Ascent

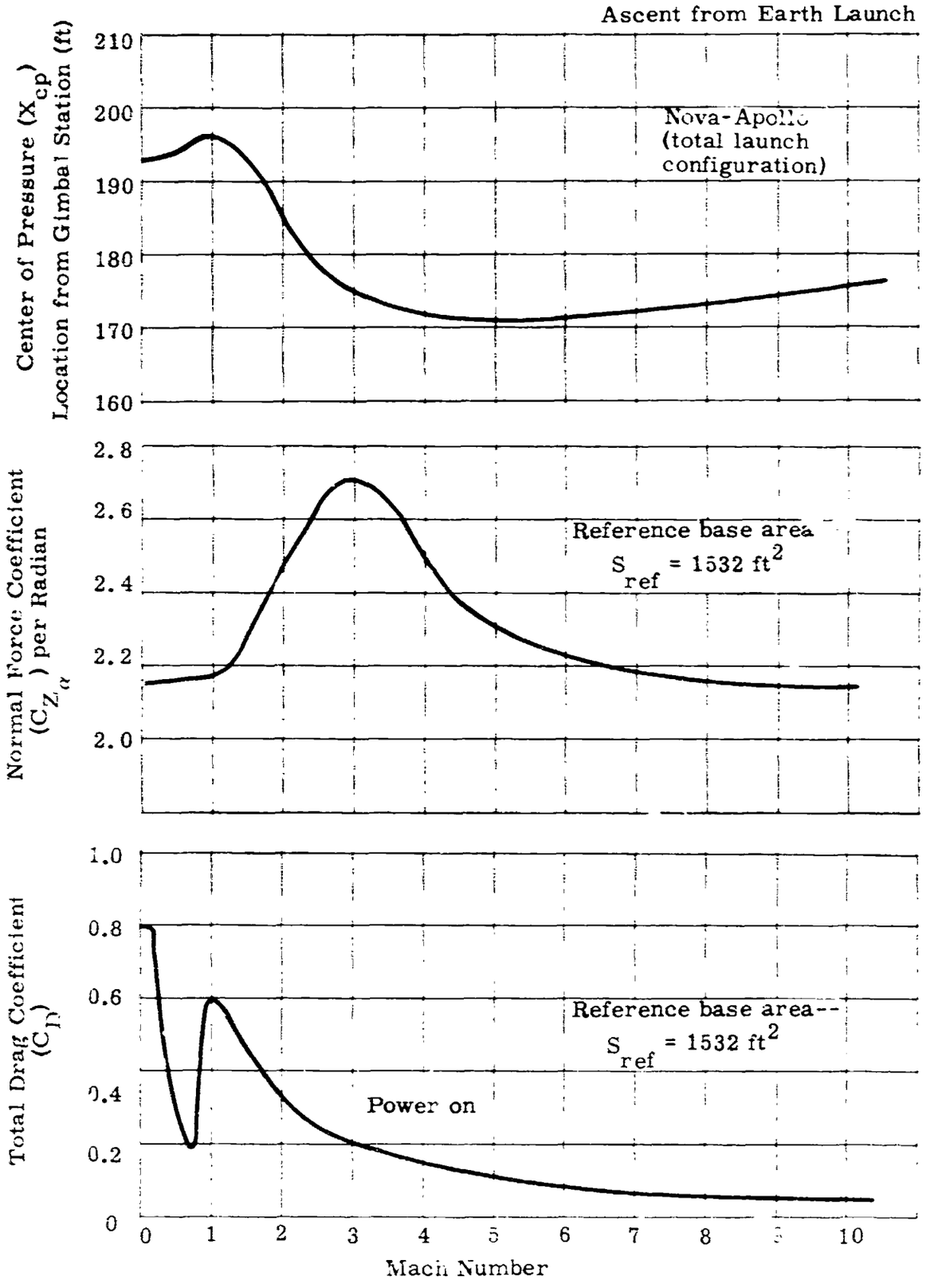


Fig. 17. Aerodynamic Data--Earth Ascent

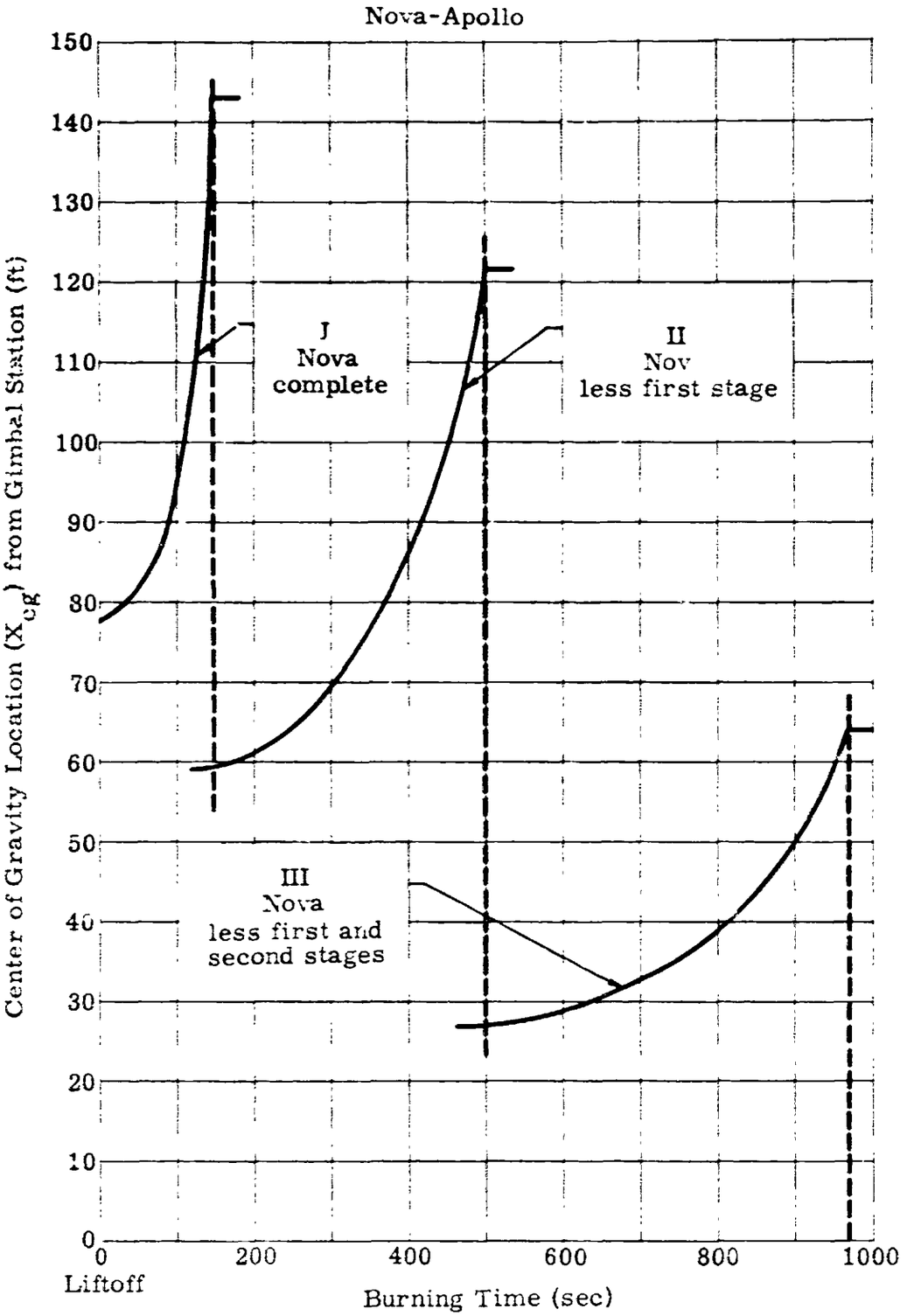


Fig. 18. CG Versus Burning Time--Earth Ascent

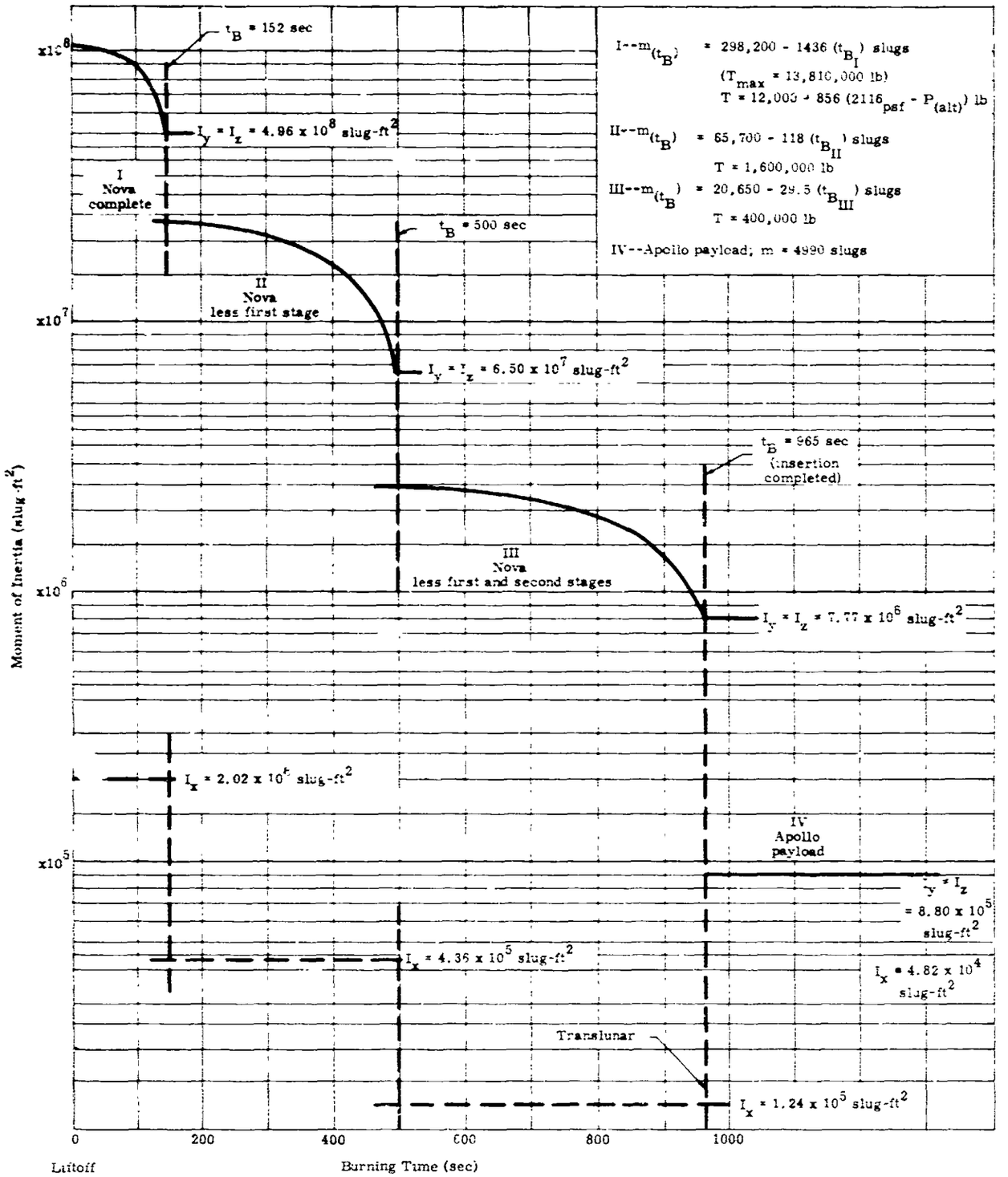


Fig. 19. Moment of Inertia Versus Burning Time--Earth Ascent

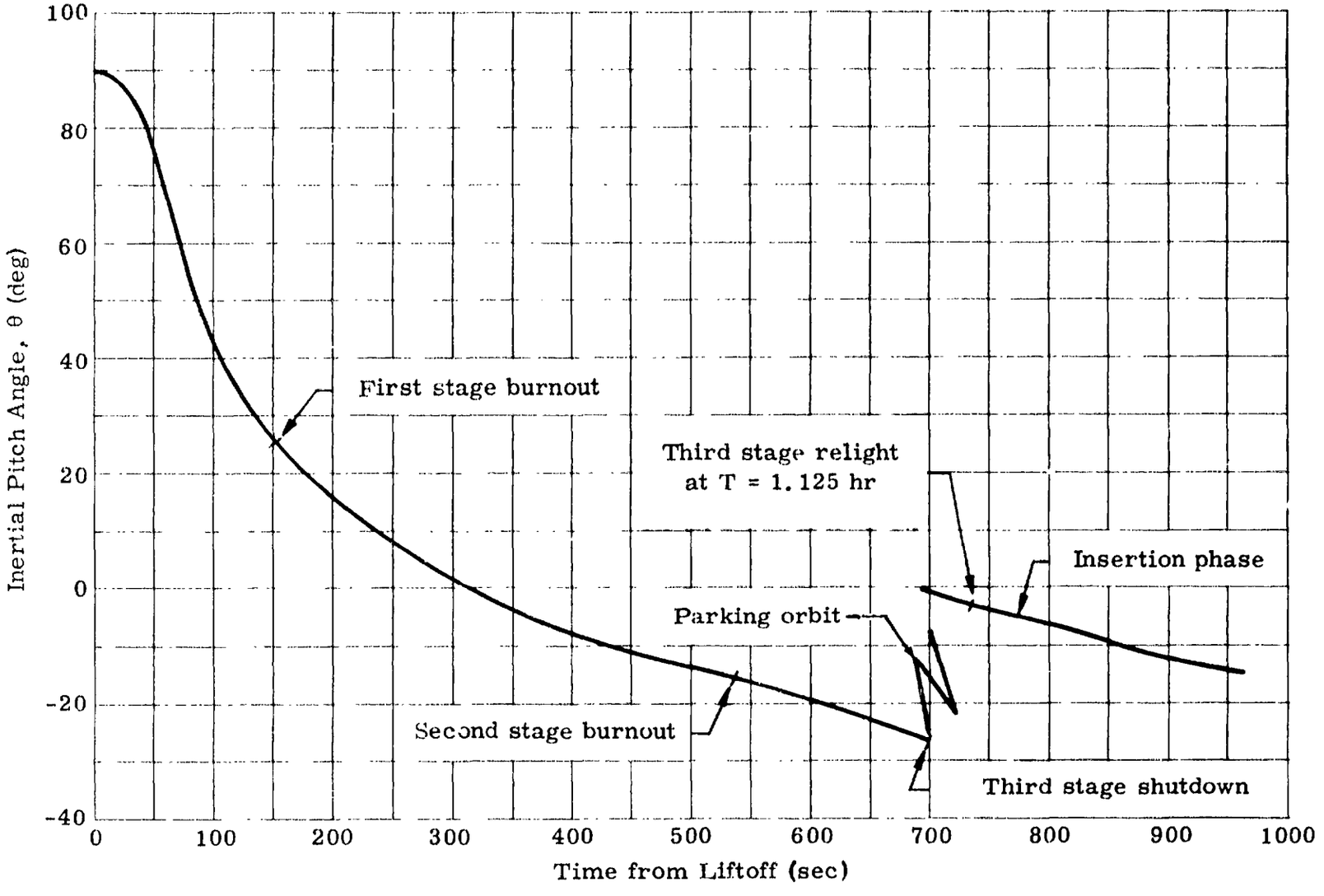


Fig. 20. Pitch ogram--Earth Ascent and Translunar Injection

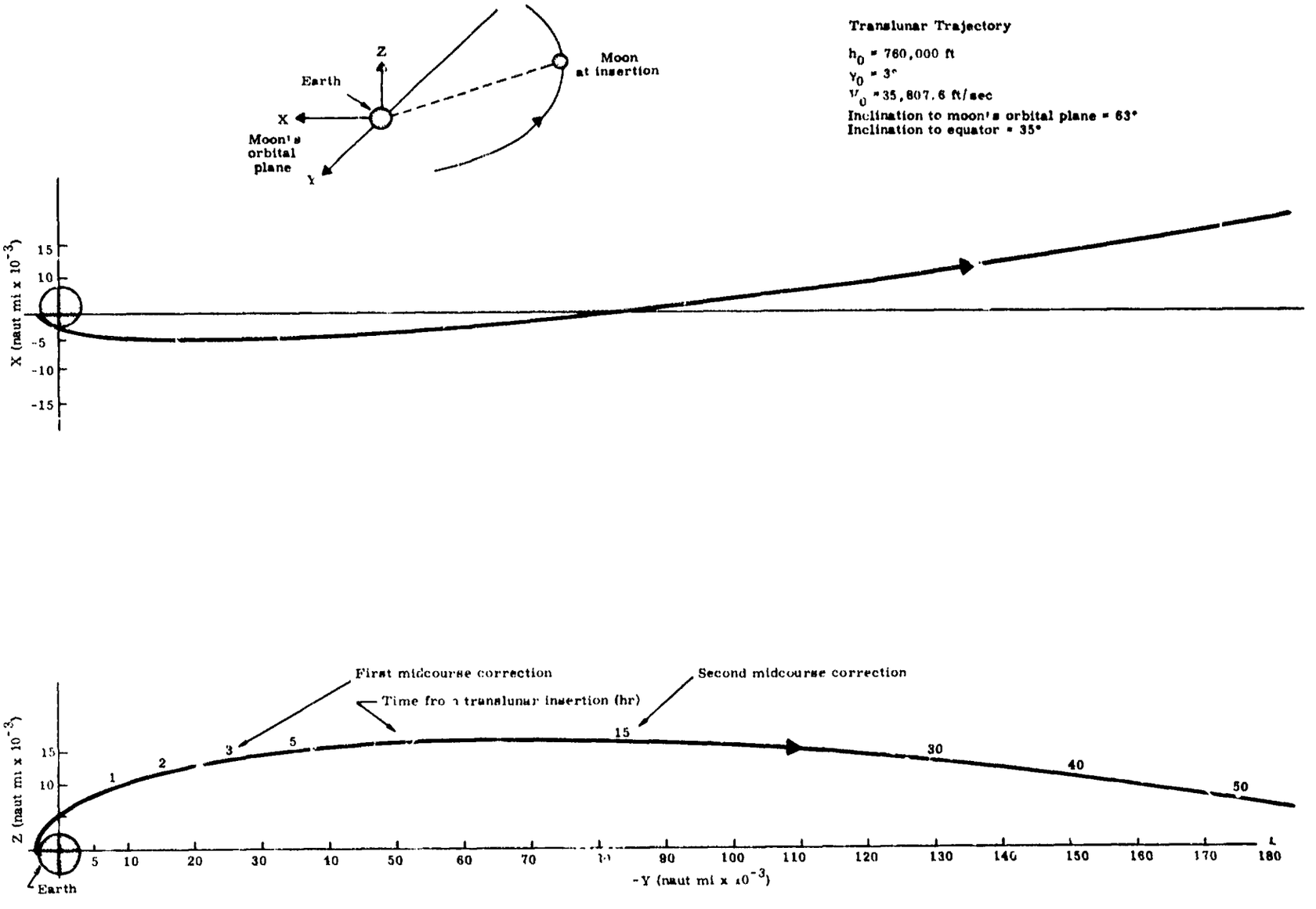


Fig. 21. Transl[illegible]rajectory--Leaving Earth

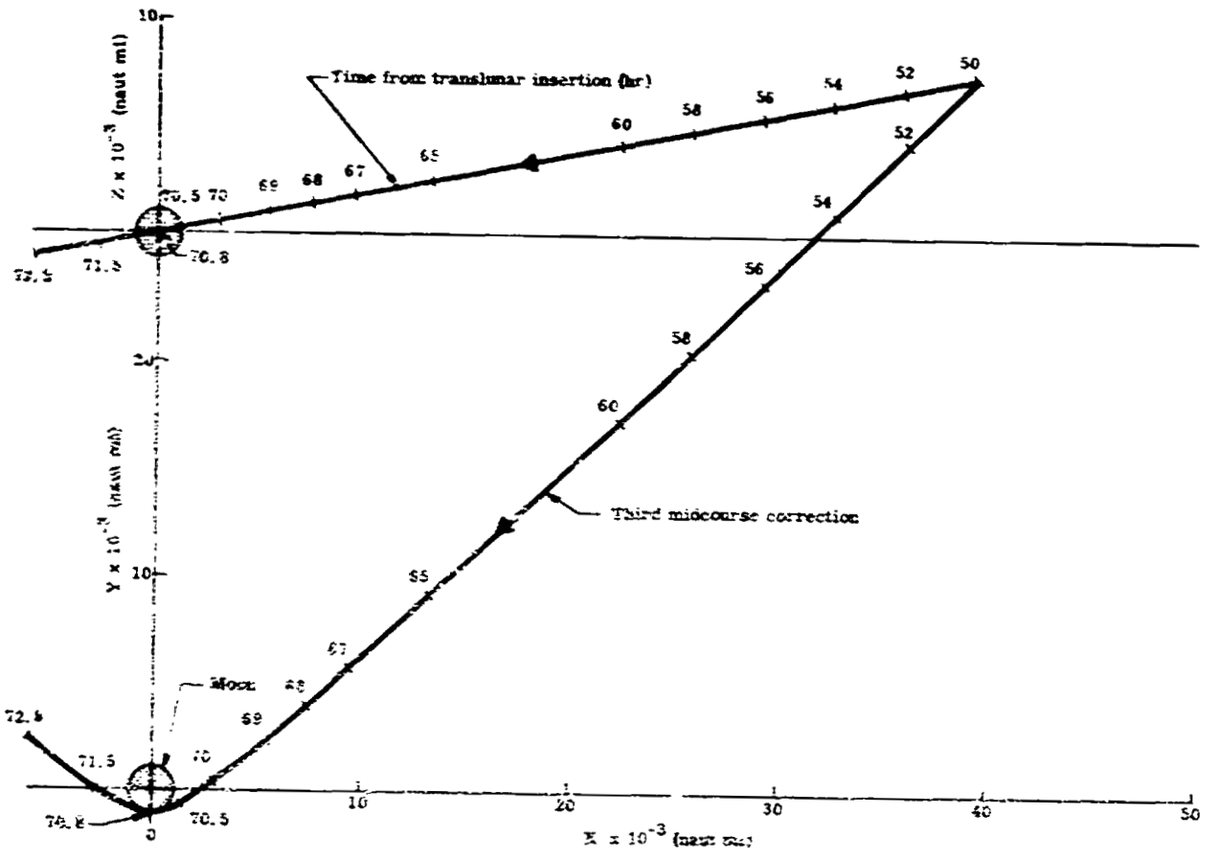


Fig. 22. Translunar Trajectory--Moon Approach

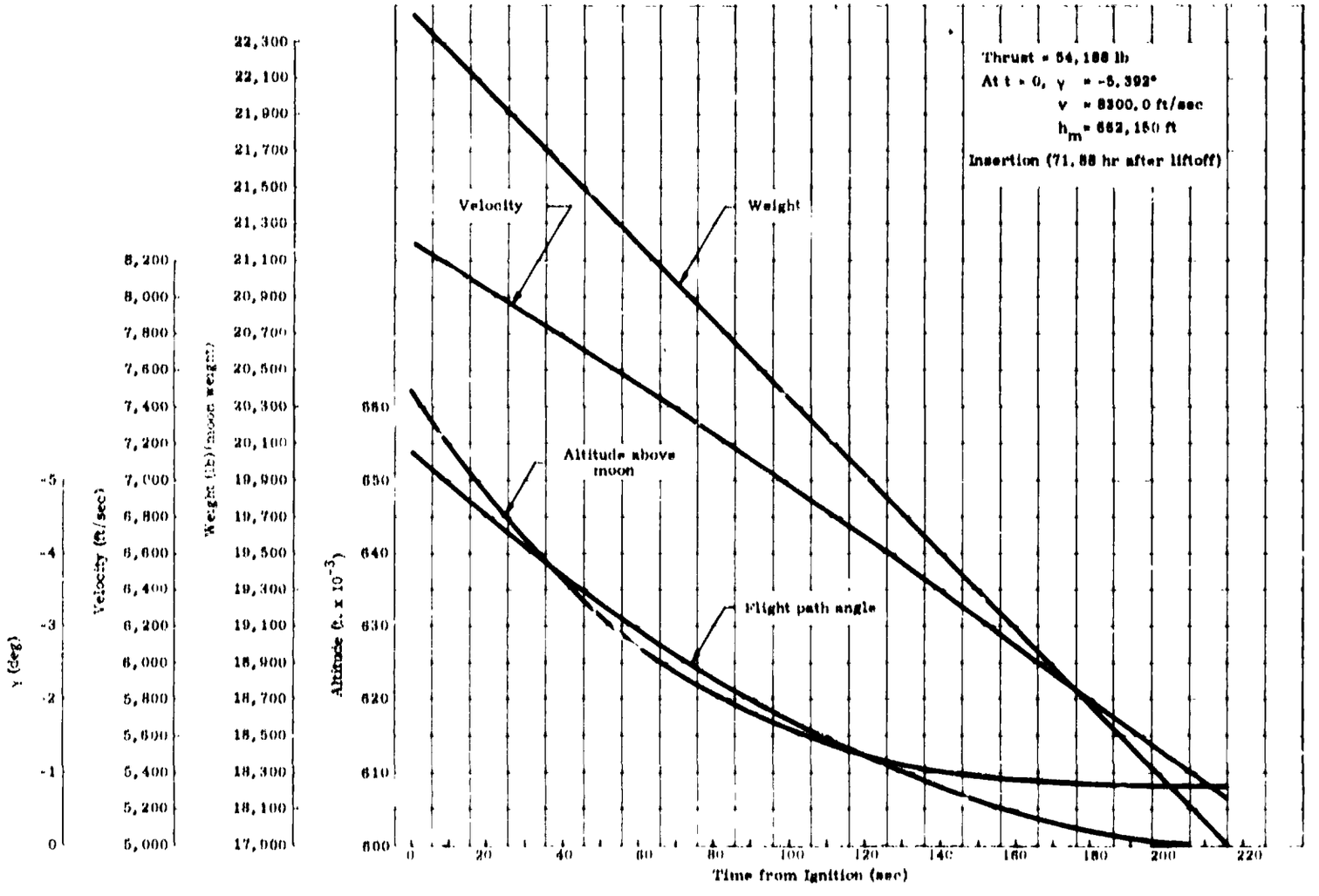


Fig. 23. Trajectory Parameters--Insertion

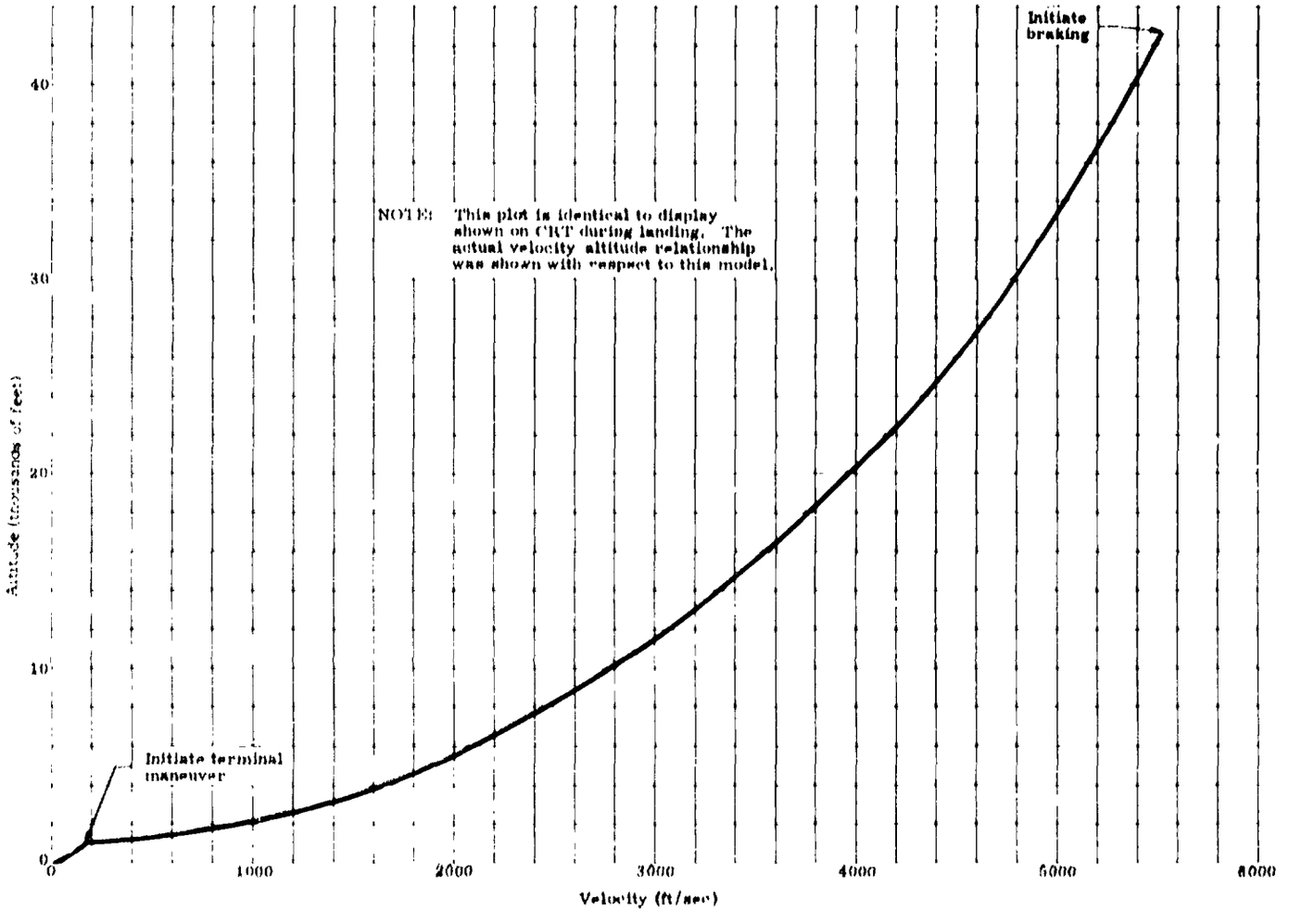


Fig. 24. Nominal Velocity Versus Altitude--Lunar Landing

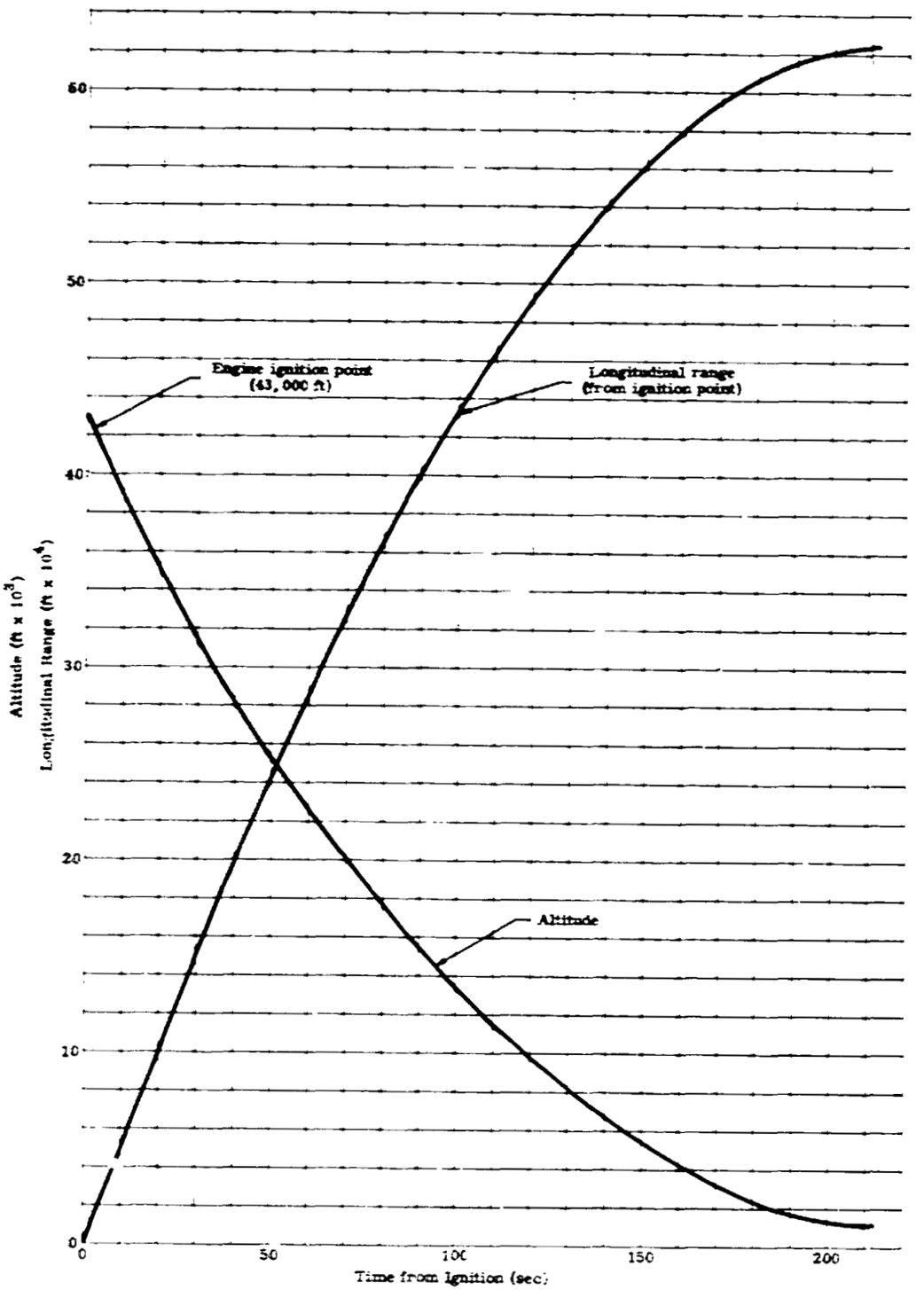


Fig. 25. Altitude and Range Versus Time--Lunar Landing

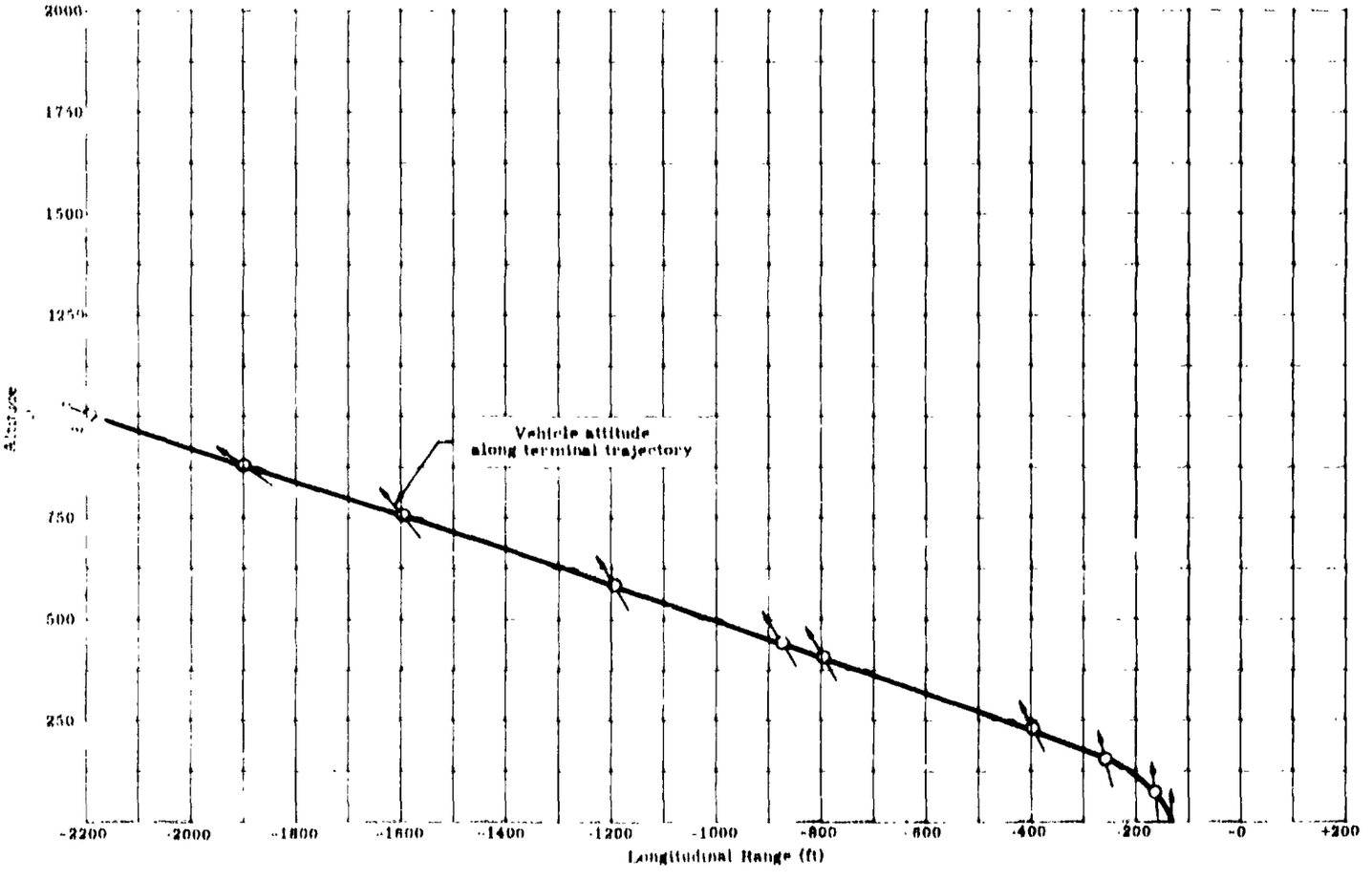


Fig. 26. Altitude Versus Range--Lunar Landing Terminal

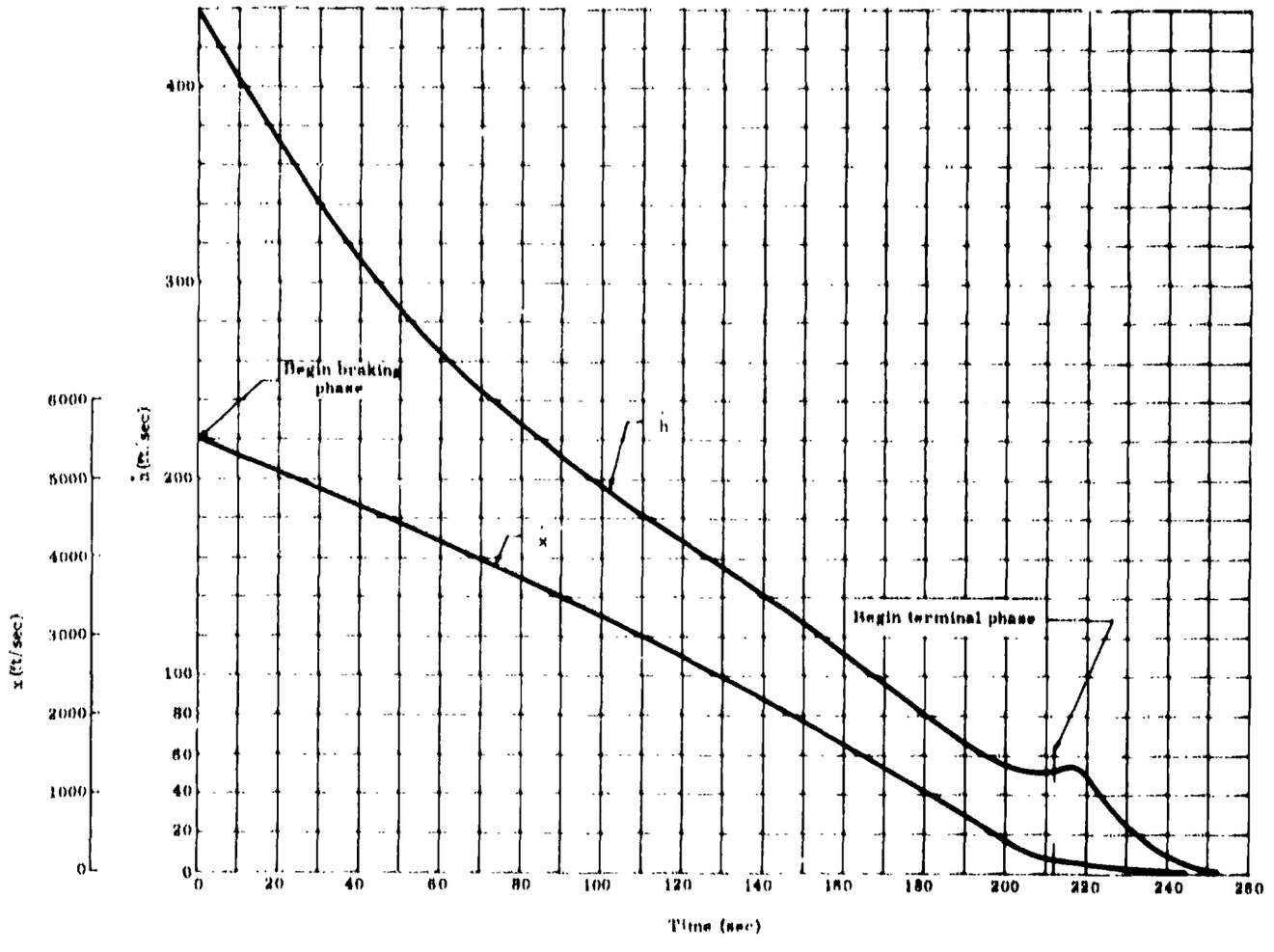


Fig. 27. Range Rate and Altitude Rate Versus Time--Lunar Landing

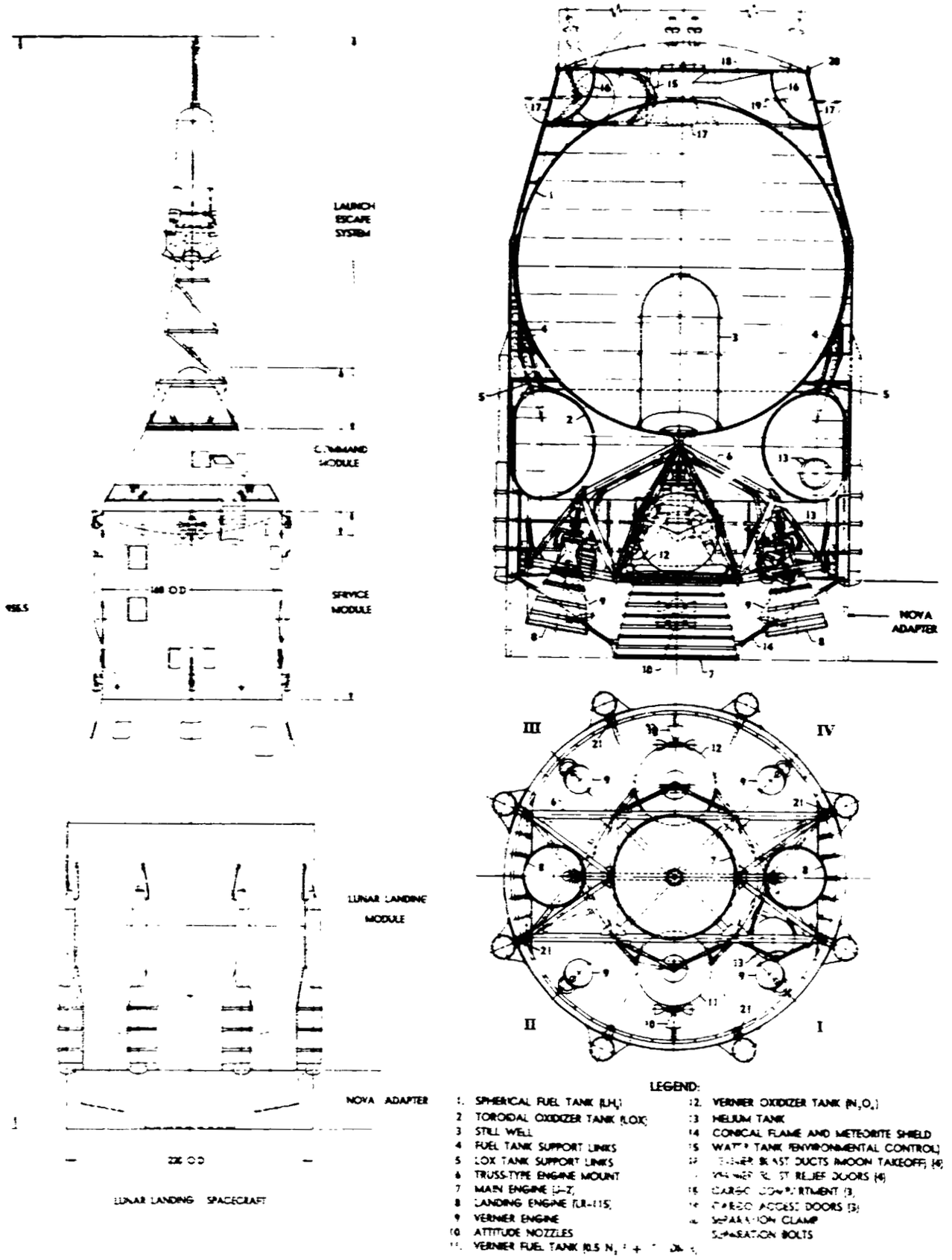
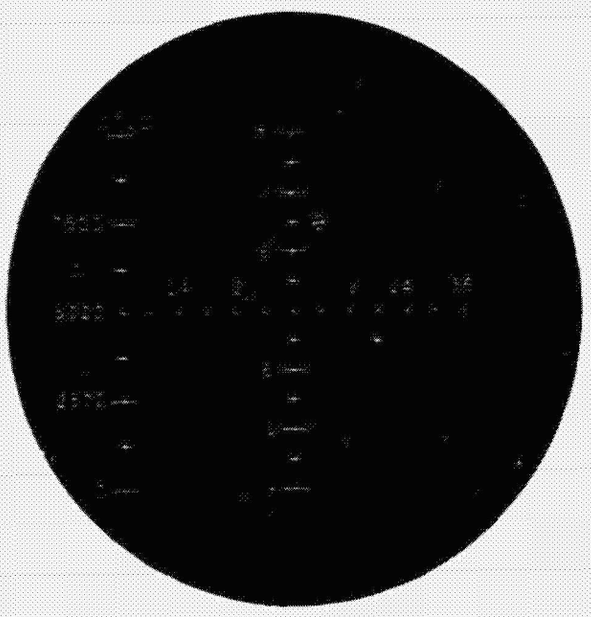
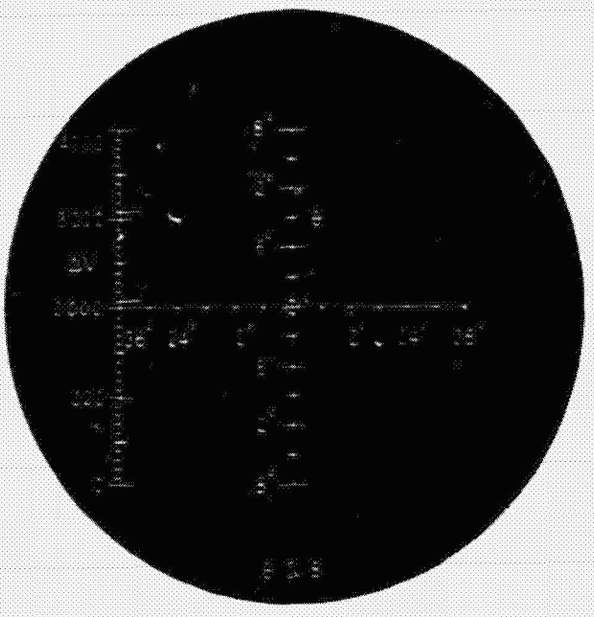


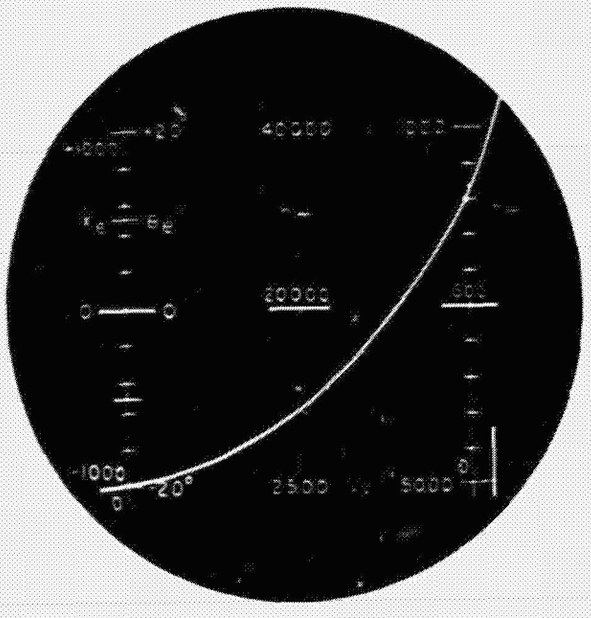
Fig. 28. Lunar Landing Configuration--Main Vehicle



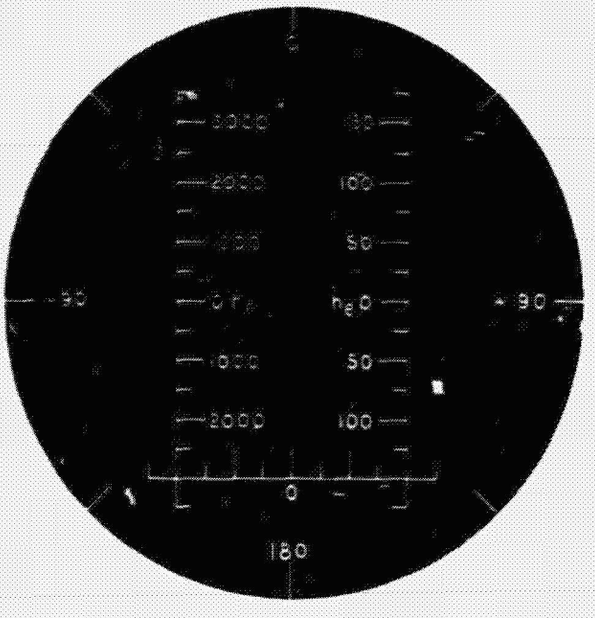
A. Translunar Insertion Display



B. Lunar Orbit Insertion Display



C. Lunar Landing Display



D. R-Entry Display

Fig. 29. CRT Displays

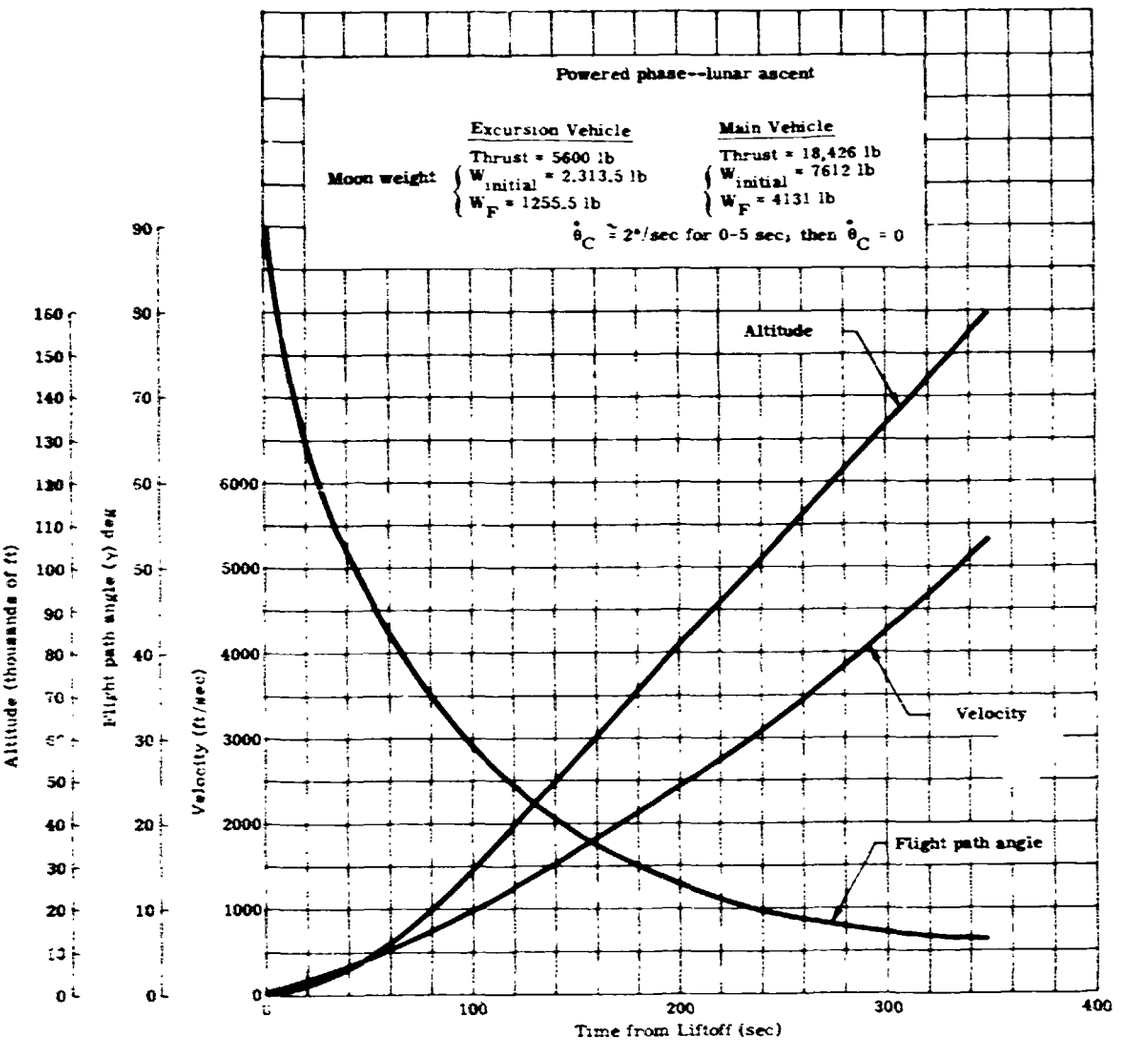


Fig. 30. Lunar Ascent Model Trajectory--Powered Phase

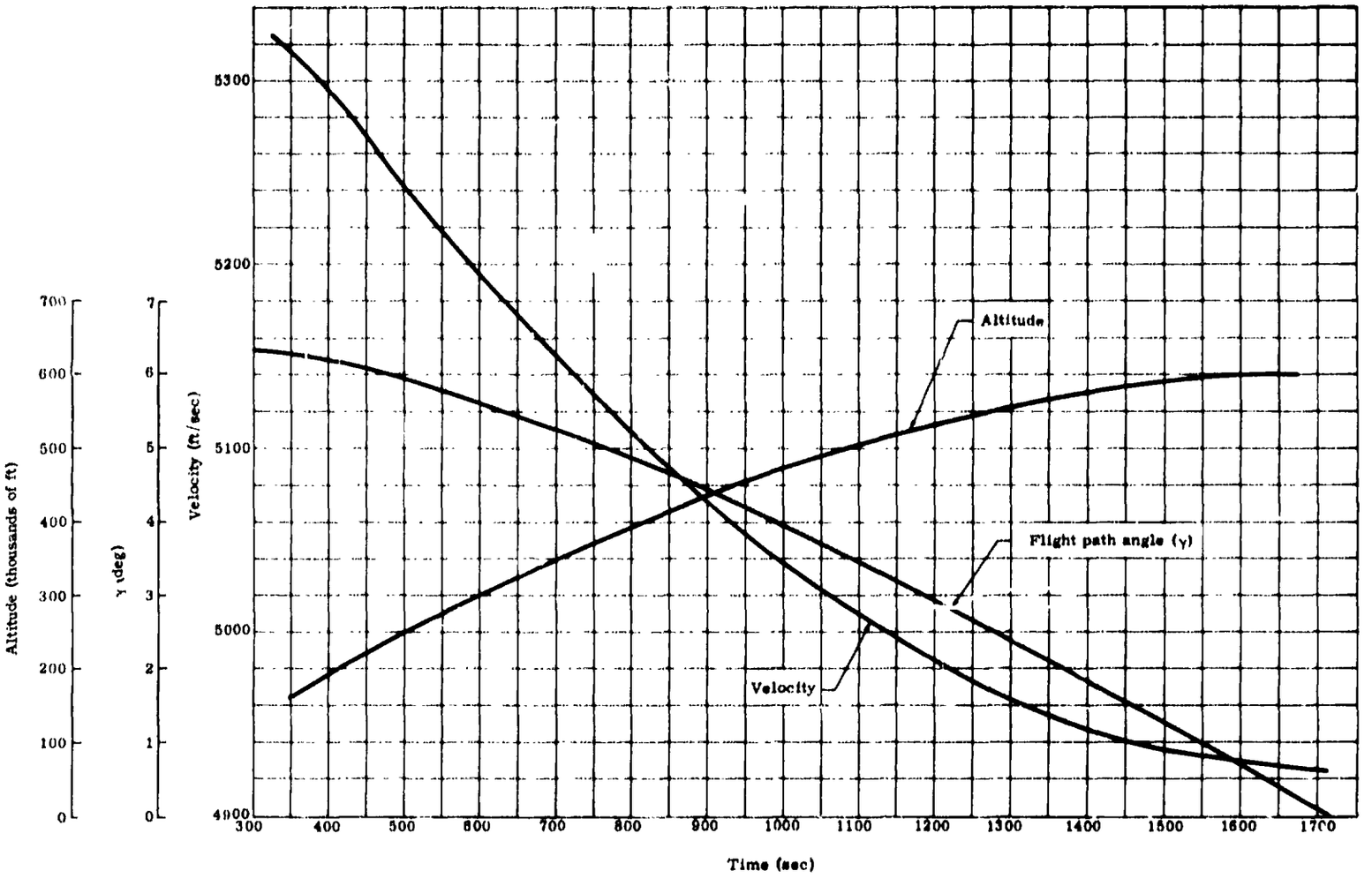


Fig. 31. Lunar Ascent Model Trajectory--Coasting Phase

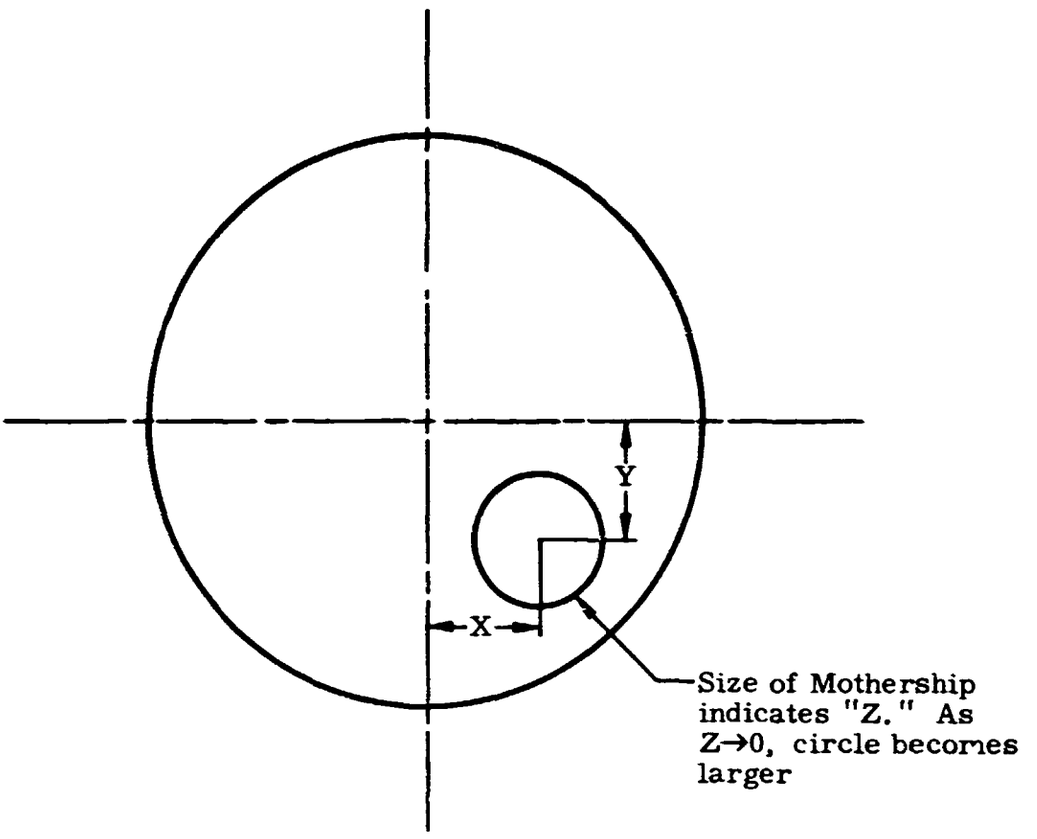


Fig. 32. CRT Rendezvous Display

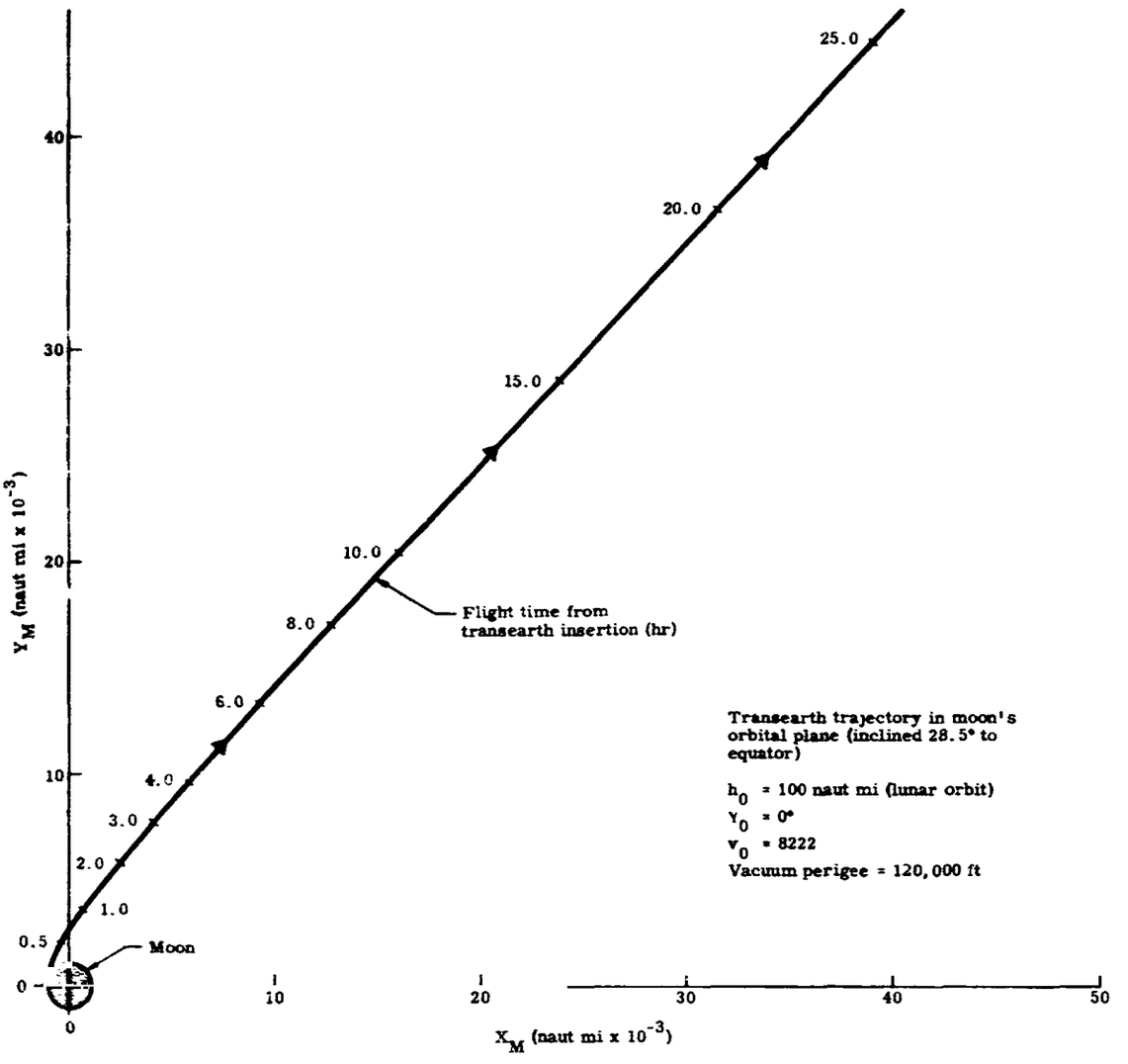


Fig. 33. Transearth Trajectory--Leaving Moon

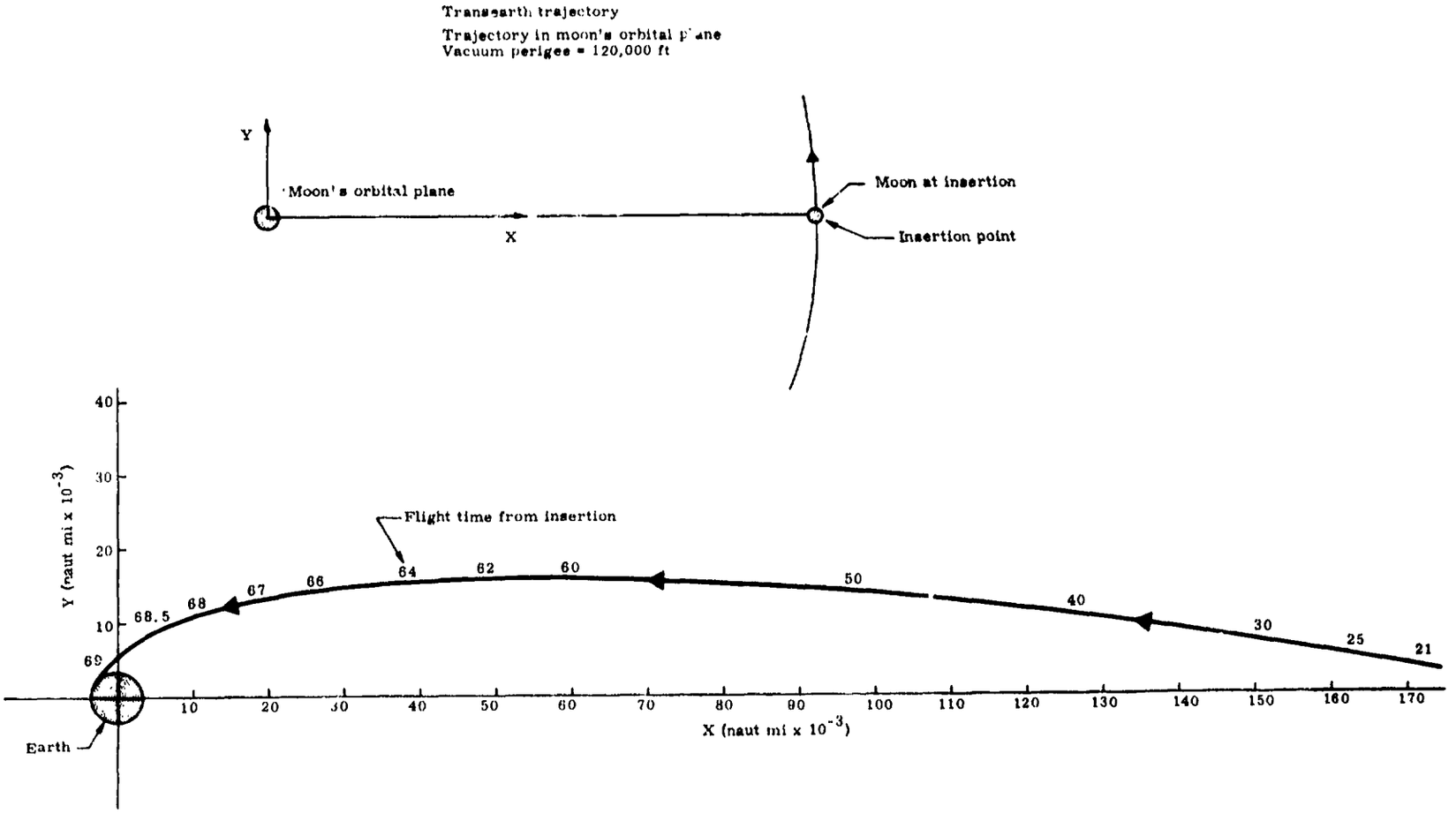


Fig. 34. Transearth Trajectory--Earth Approach

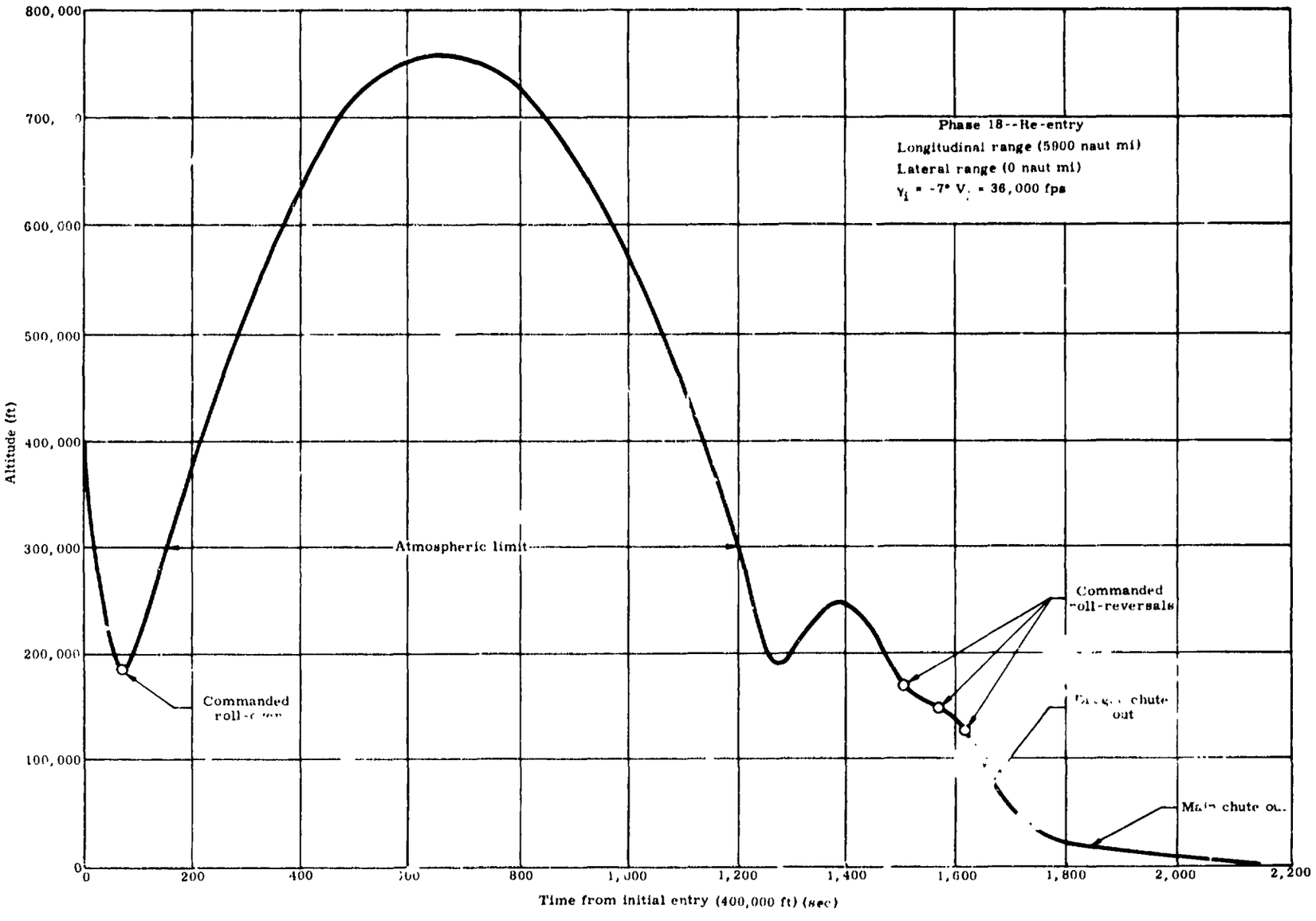
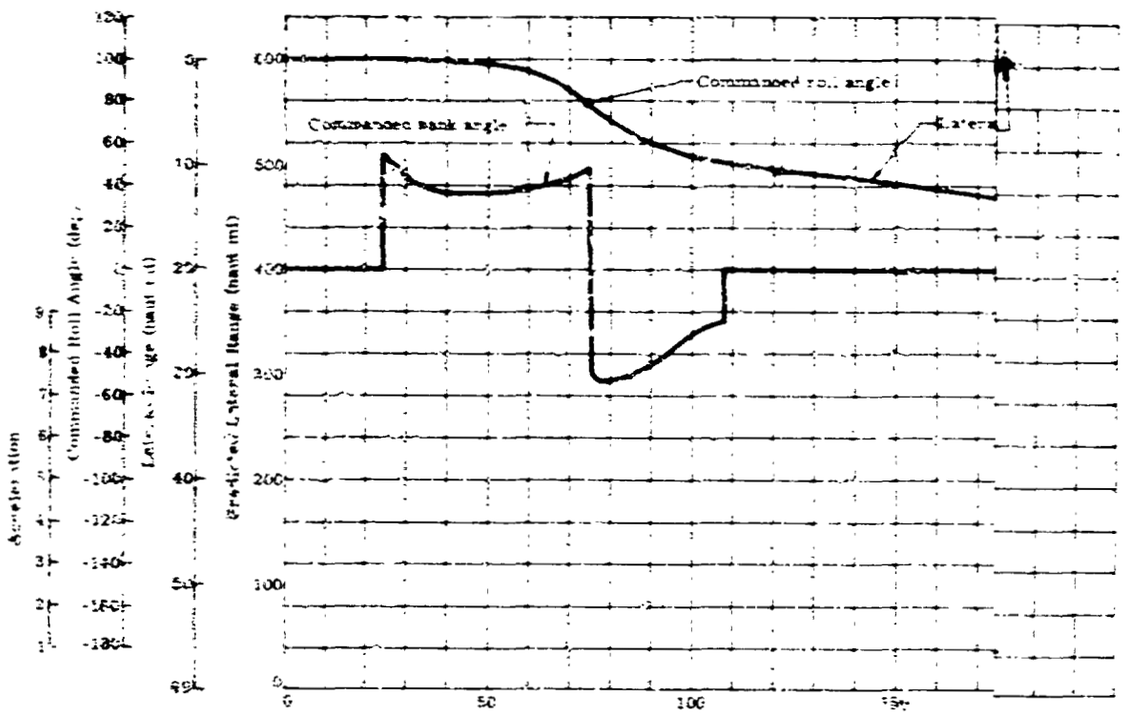
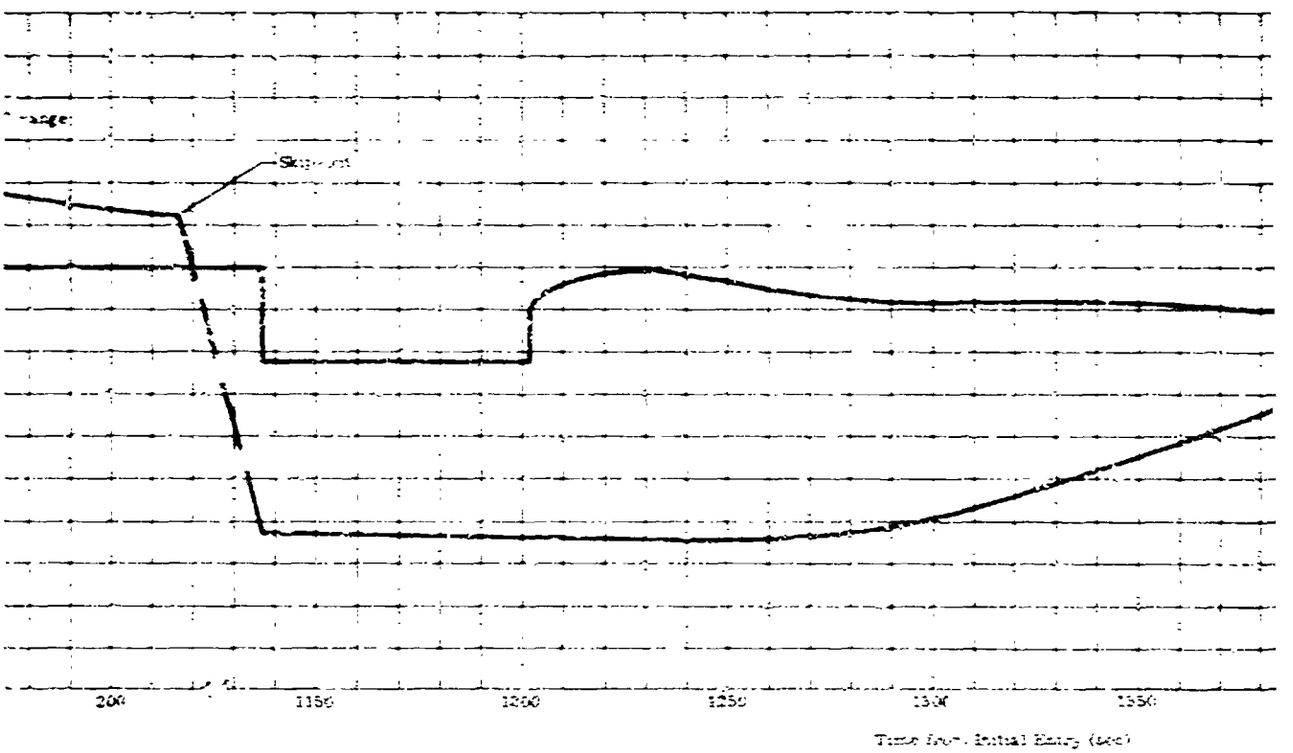


Fig. 35. Altitude Versus Time--Re-entry


Commanded roll angle
Commanded bank angle
Predicted Lateral Range (nautical miles)
0
50
100
500
400
300
200
100

Re-entry


1150
1200
1250
1300
1350

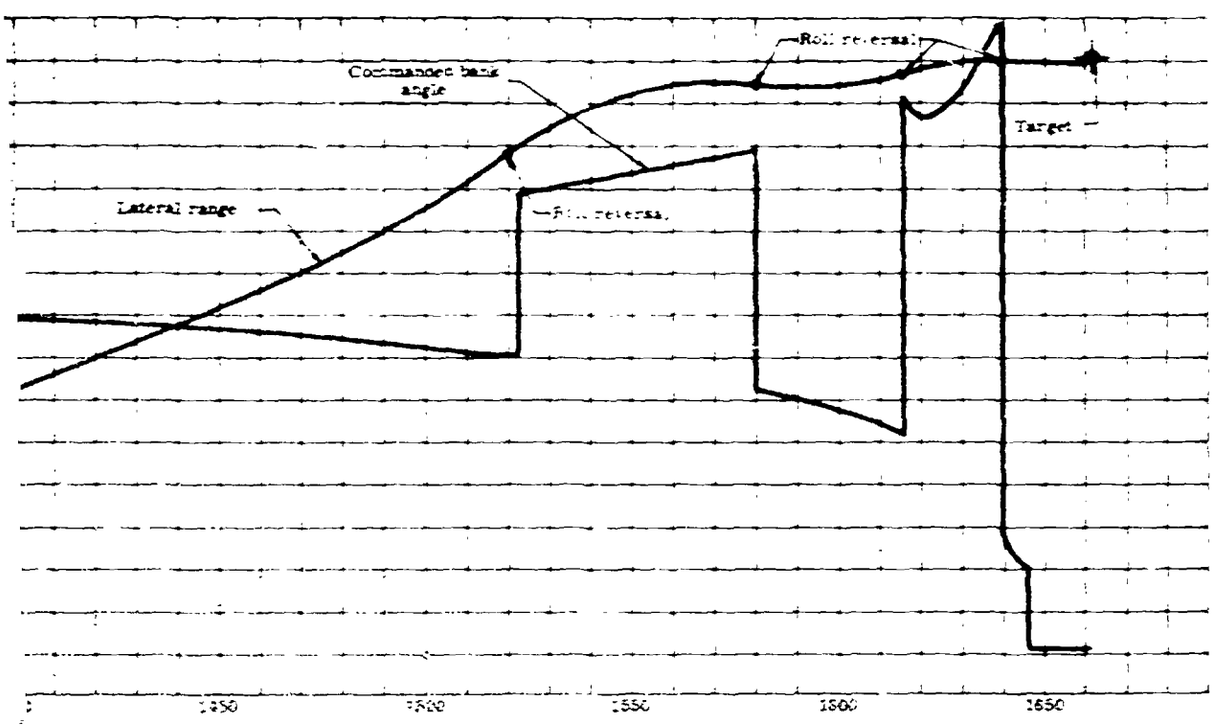


Fig. 36. Commanded Roll Angle and Lateral Range Versus Time--Re-entry

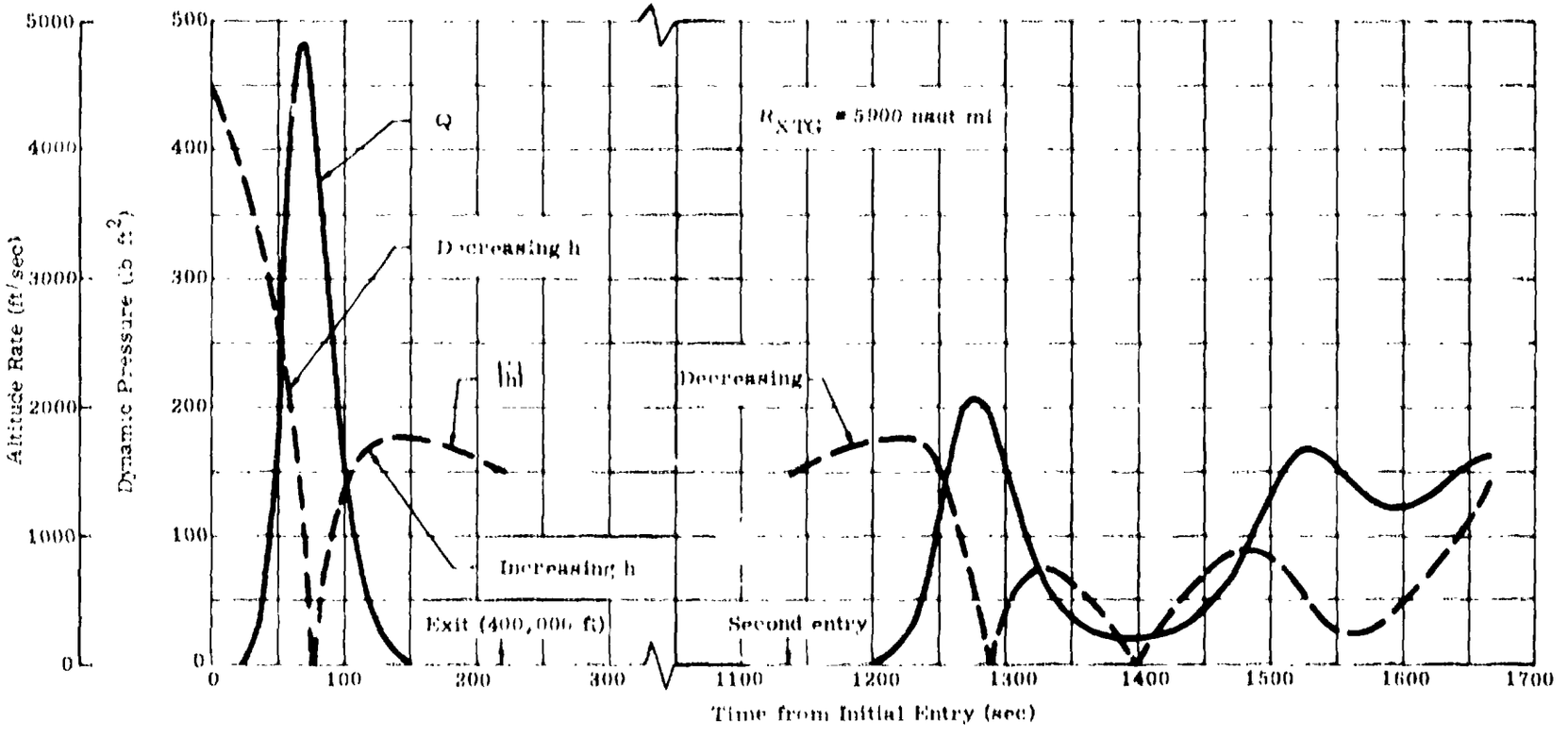
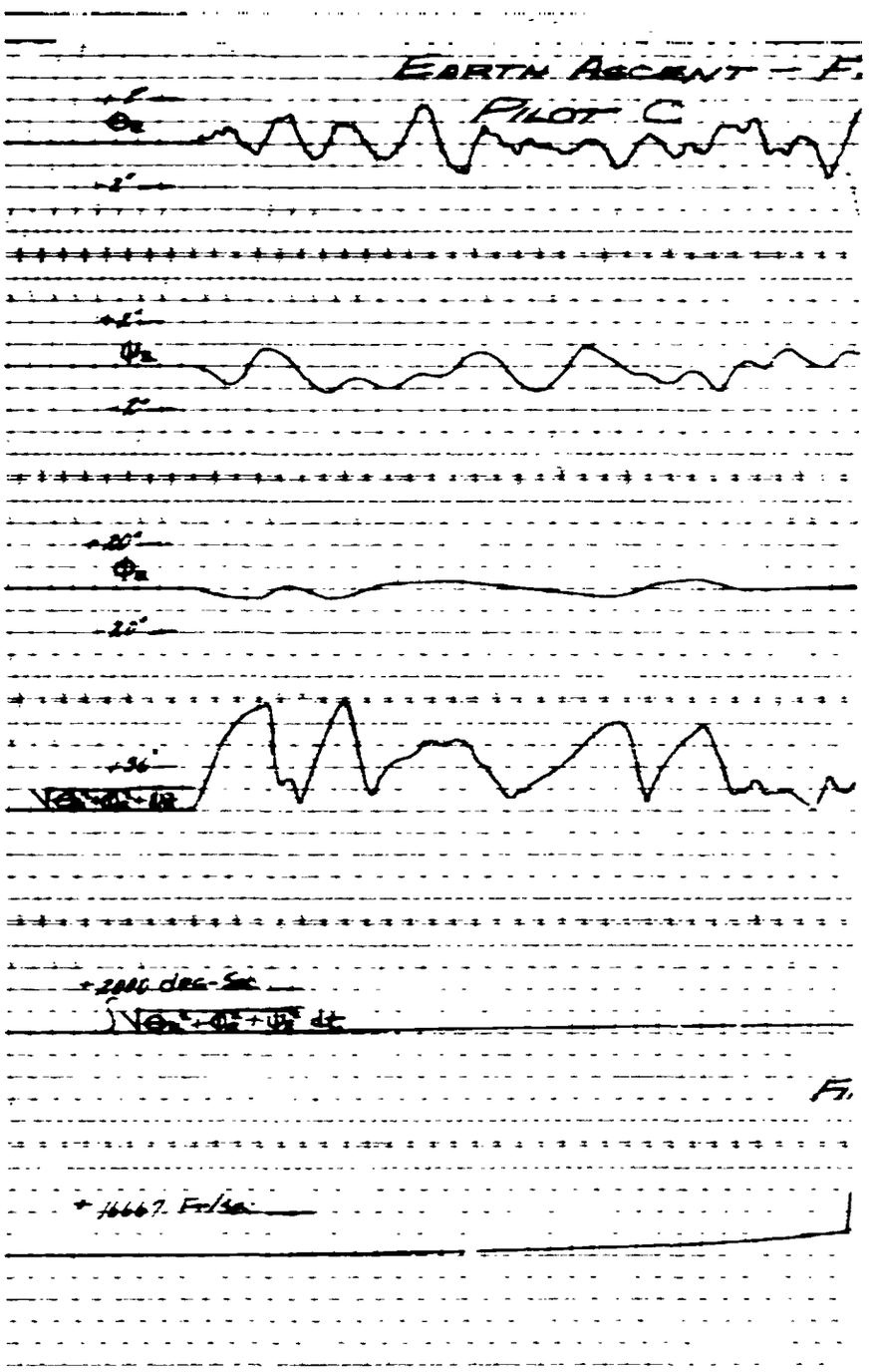
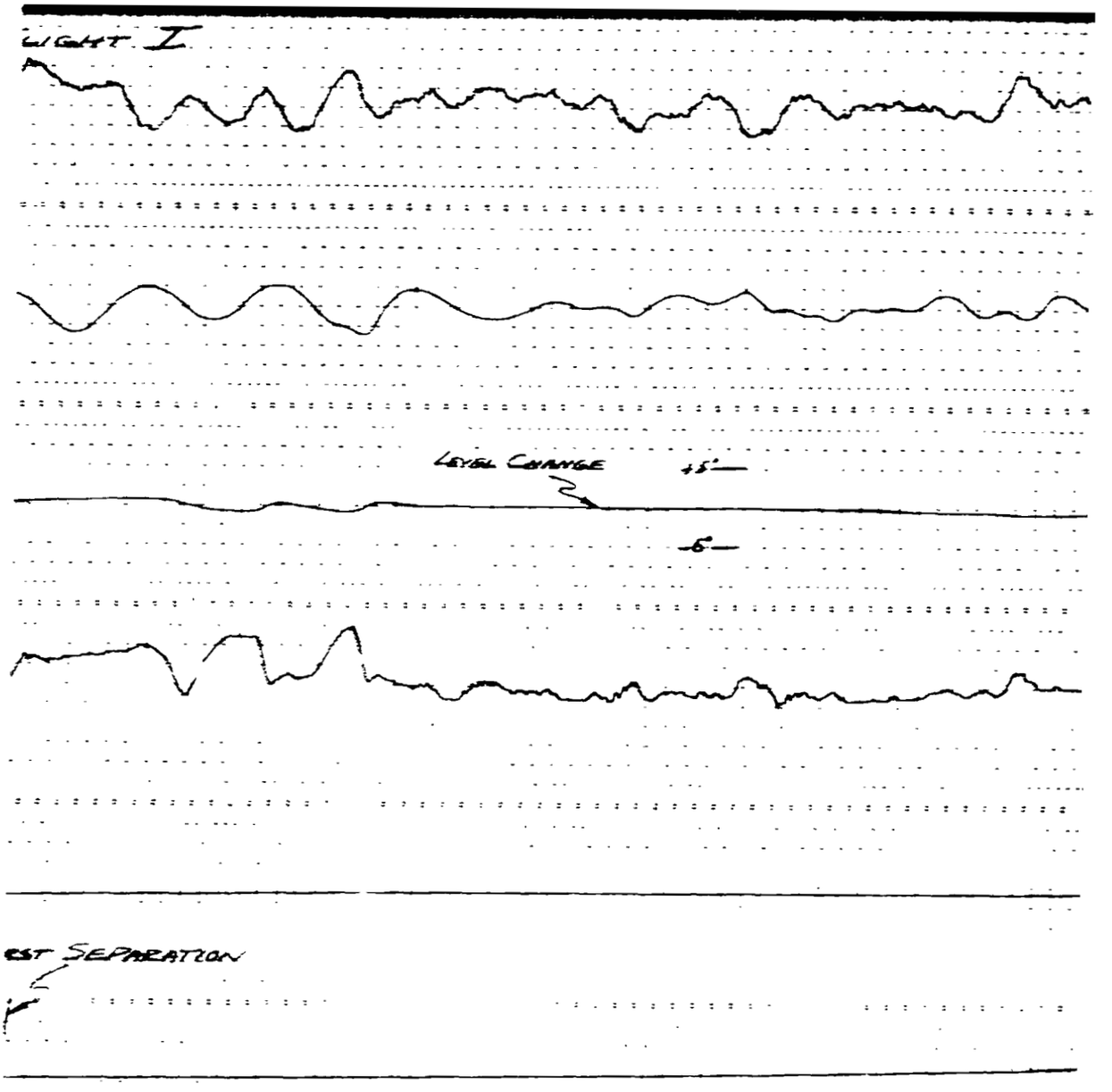


Fig. 37. Altitude Rate and Dynamic Pressure Versus Time--Re-entry



. Ascent


LIGHT I
LEVEL CHANGE
45'
6'
EST SEPARATION

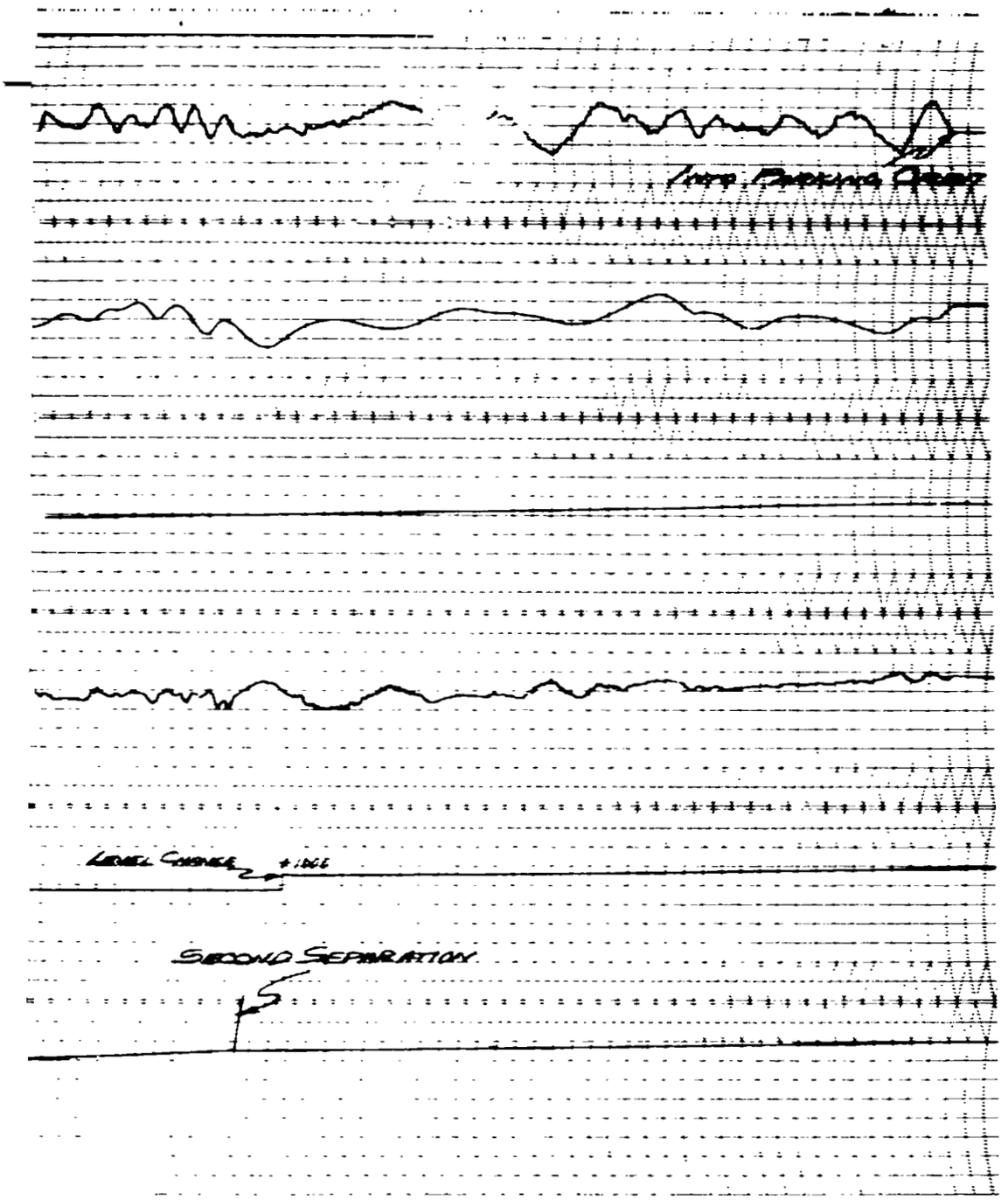


Fig. 38. Analog Flight Recording--Earth Ascent

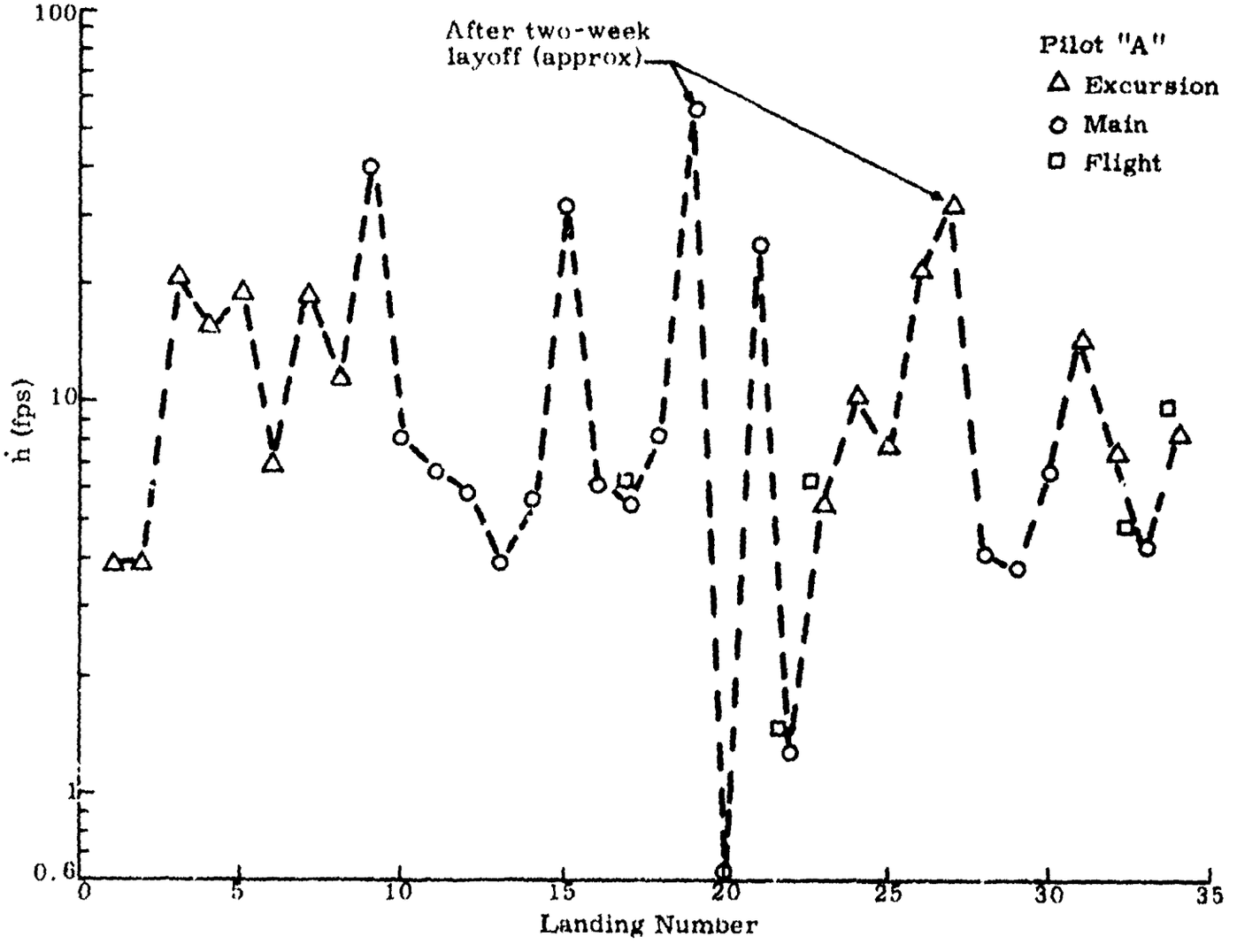


Fig. 39A. $\dot{h}$ Versus Number of Lunar Landings--Pilot "A"

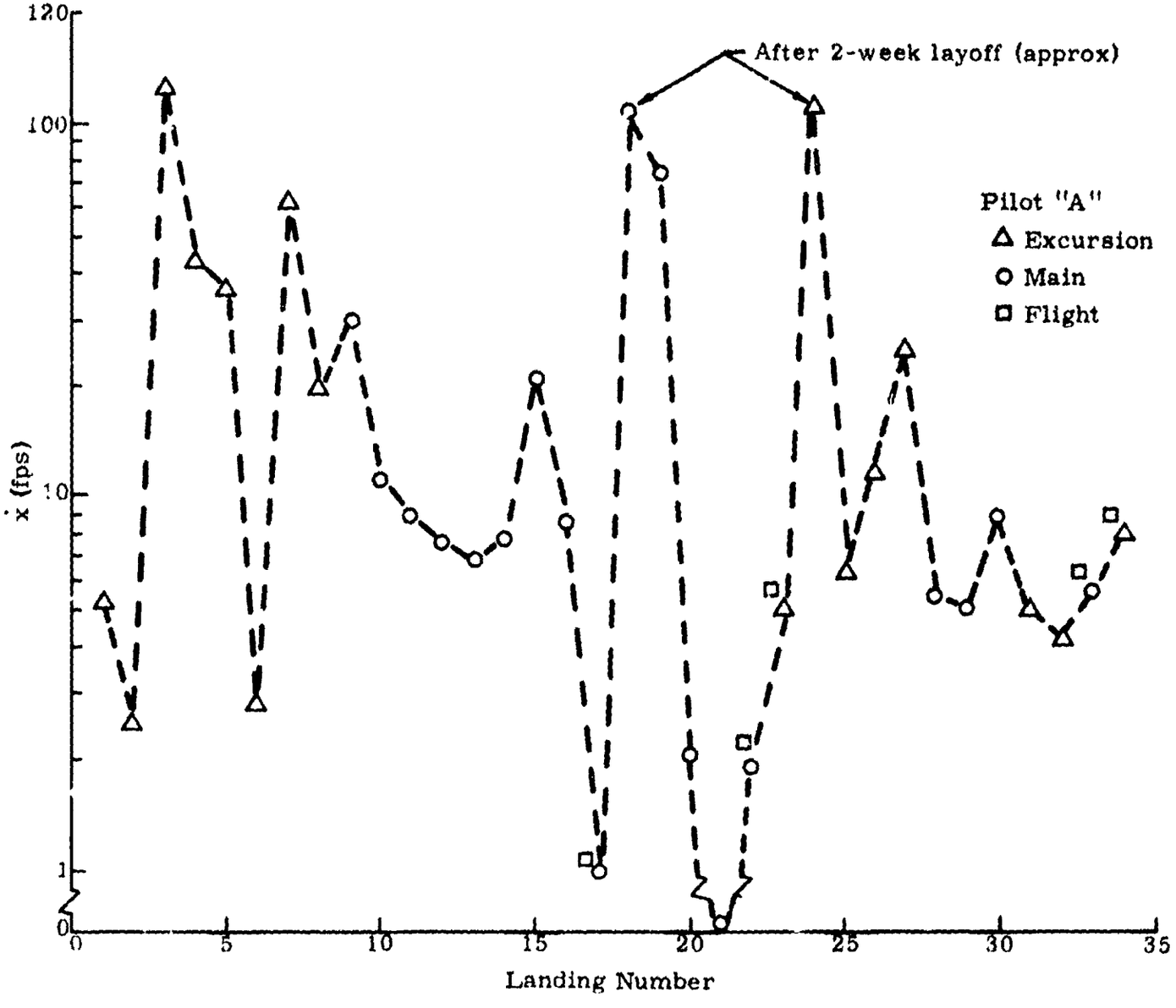


Fig. 39B. $\dot{x}$ Versus Number of Lunar Landings--Pilot "A"

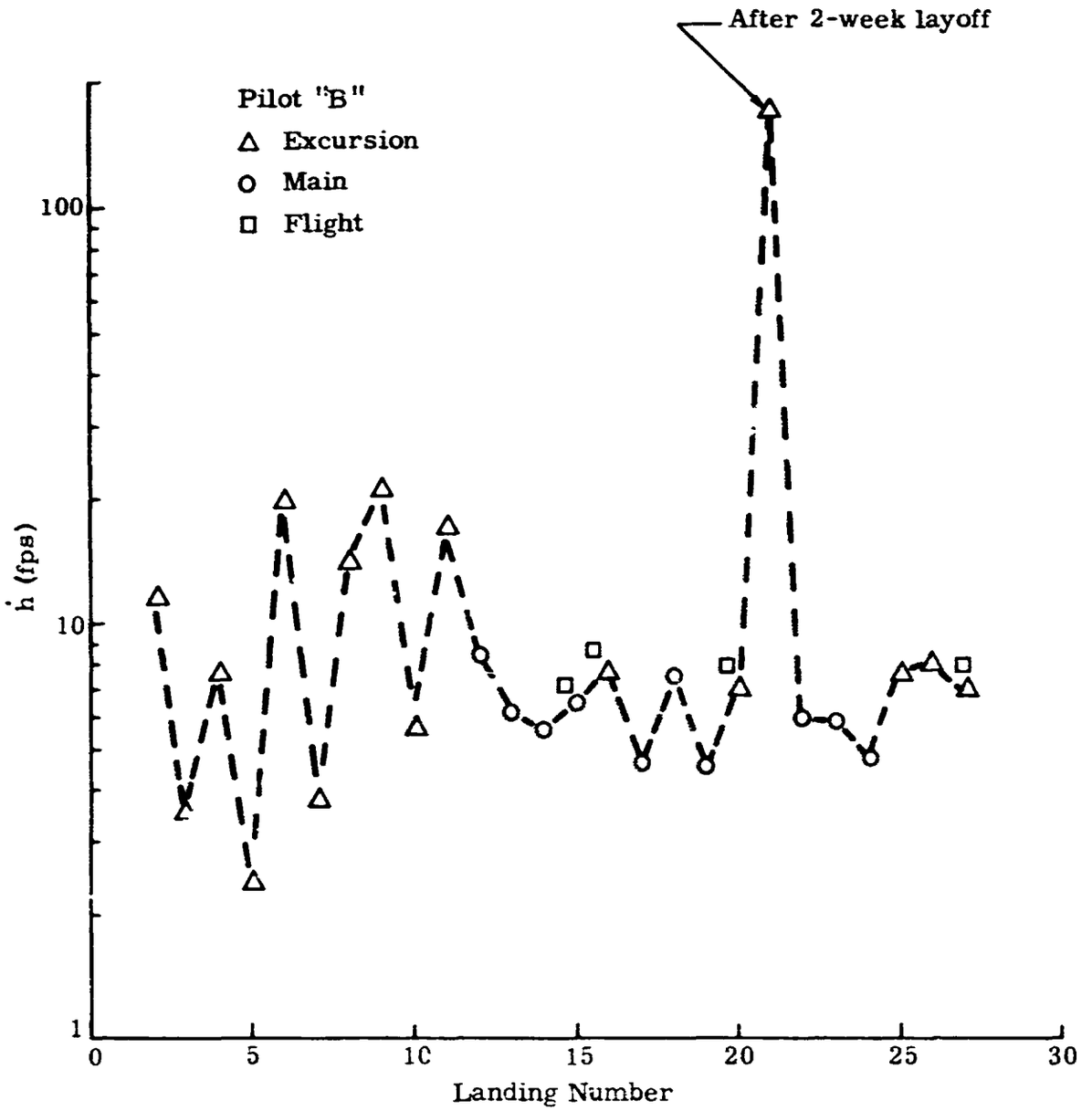


Fig. 40A. $\dot{h}$ Versus Number of Lunar Landings--Pilot "B"

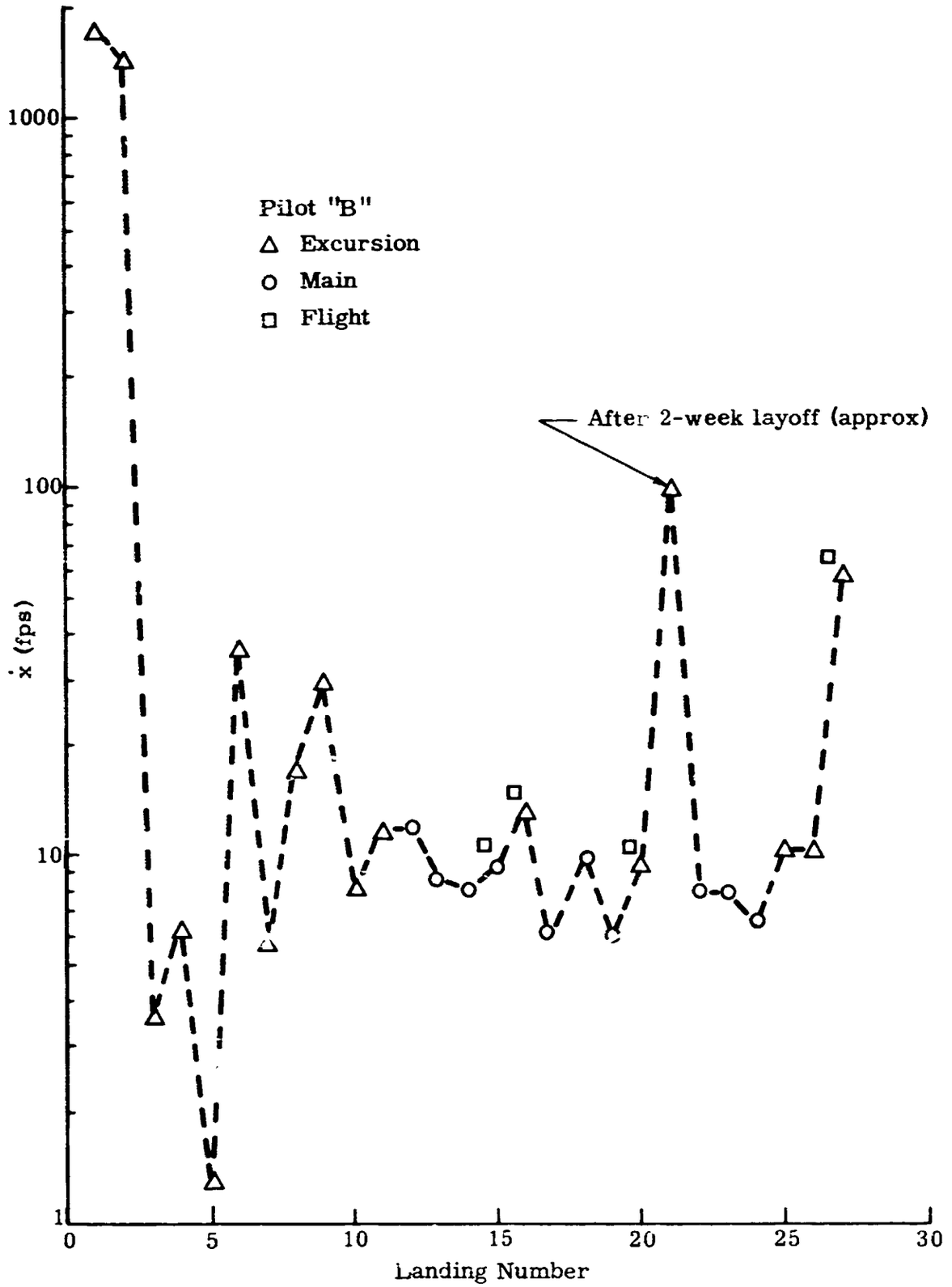


Fig. 40B. $\dot{x}$ Versus Number of Lunar Landings--Pilot "B"

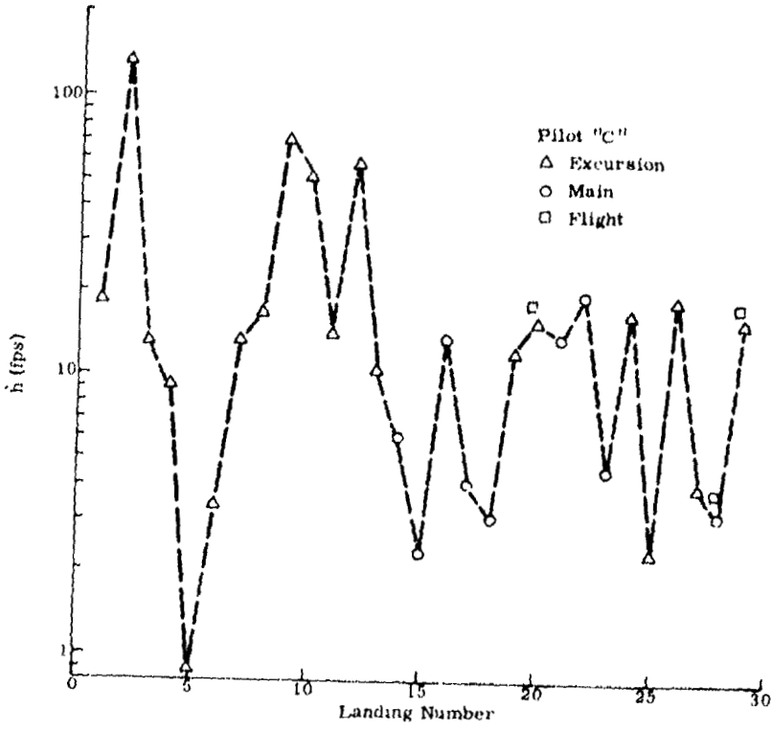


Fig. 41A. $\dot{h}$ Versus Number of Lunar Landings--Pilot "C"

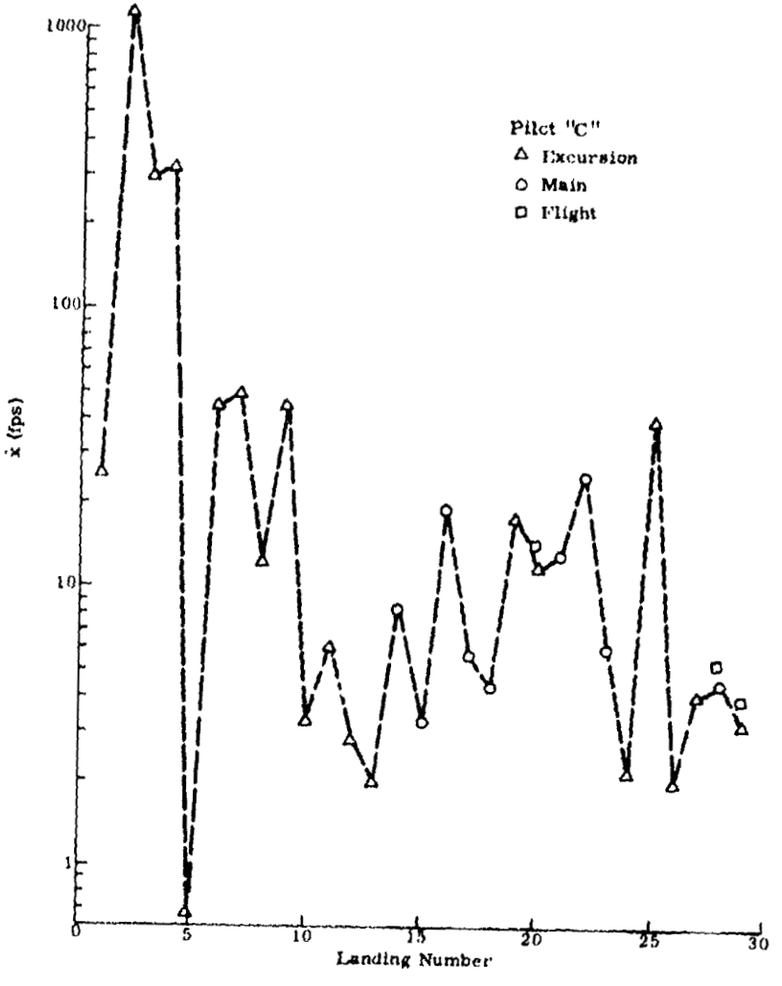


Fig. 41B. $\dot{x}$ Versus Number of Lunar Landings--Pilot "C"

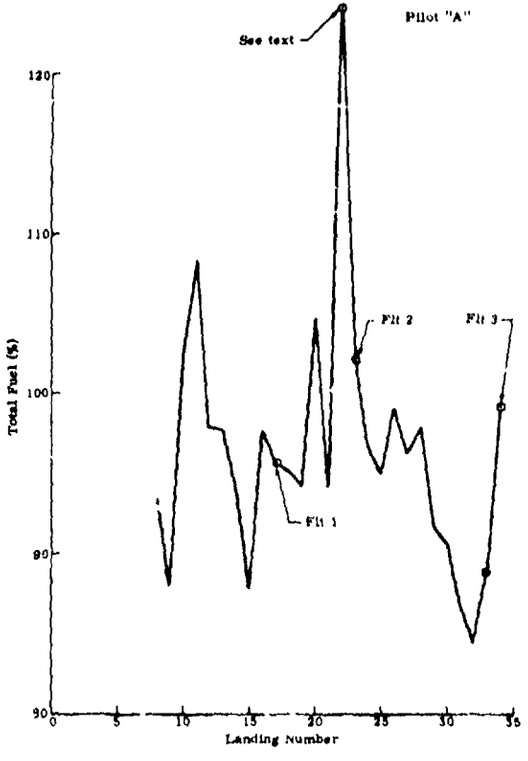


Fig. 42. Fuel Used Versus Number of Lunar Landings--Pilot "A"

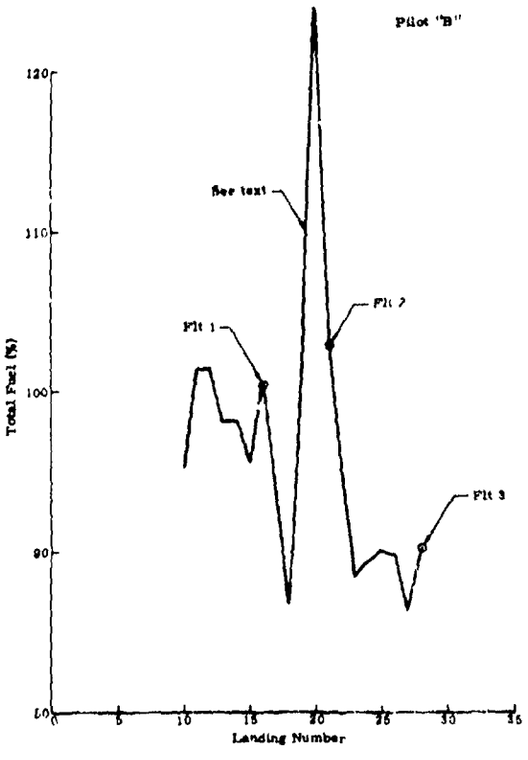


Fig. 43. Fuel Used Versus Number of Lunar Landings--Pilot "B"

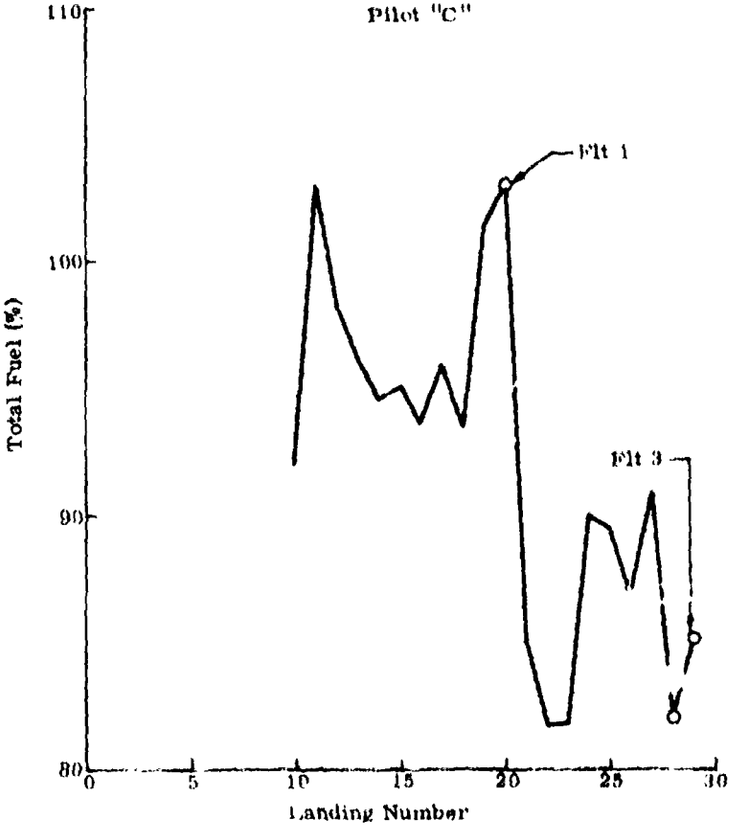


Fig. 44. Fuel Used Versus Number of Lunar Landings--Pilot "C"

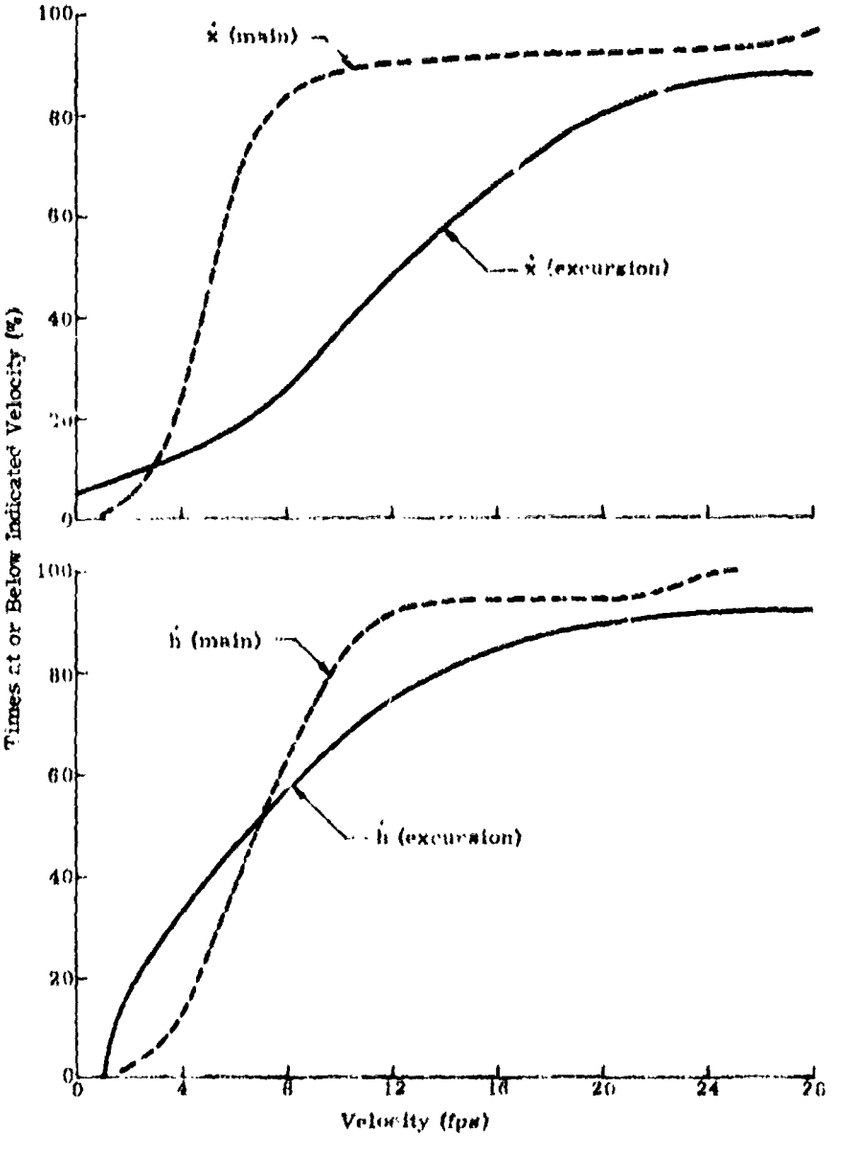


Fig. 45. Lunar Landing Terminal $\dot{h}$ and $\dot{x}$--Excursion Versus Main Vehicles--All Baseline

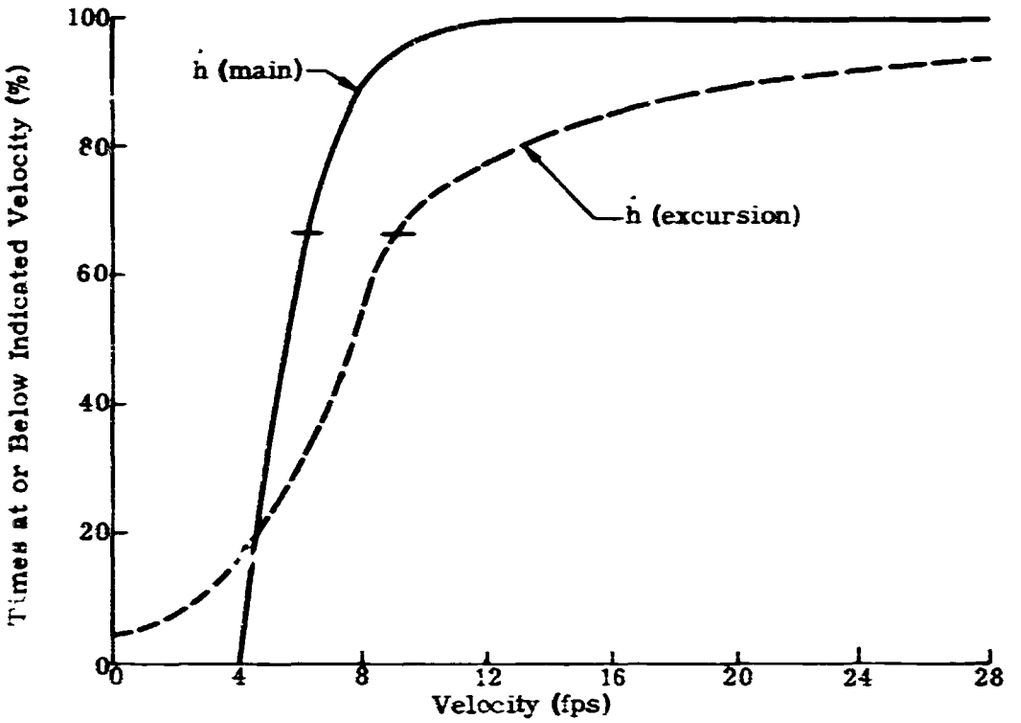


Fig. 46. Lunar Landing Terminal h--Excursion Versus Main Vehicles--Pilot "B"

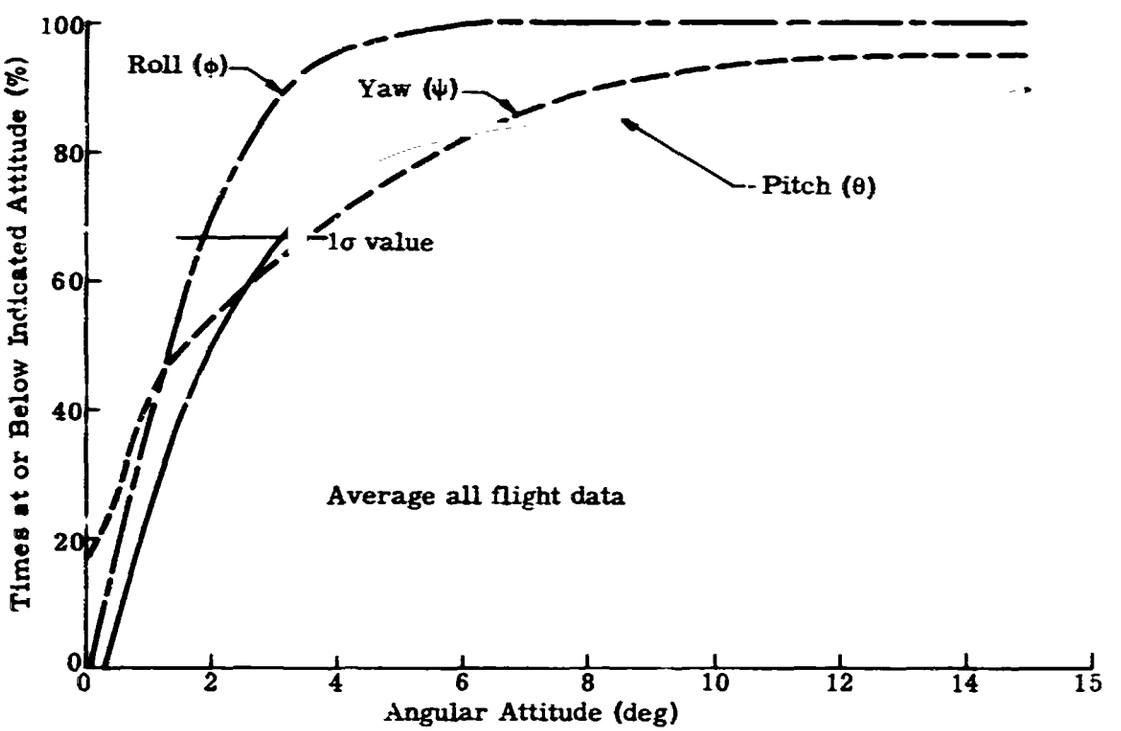


Fig. 47. Lunar Landing Terminal Body Angles--All Baseline Data

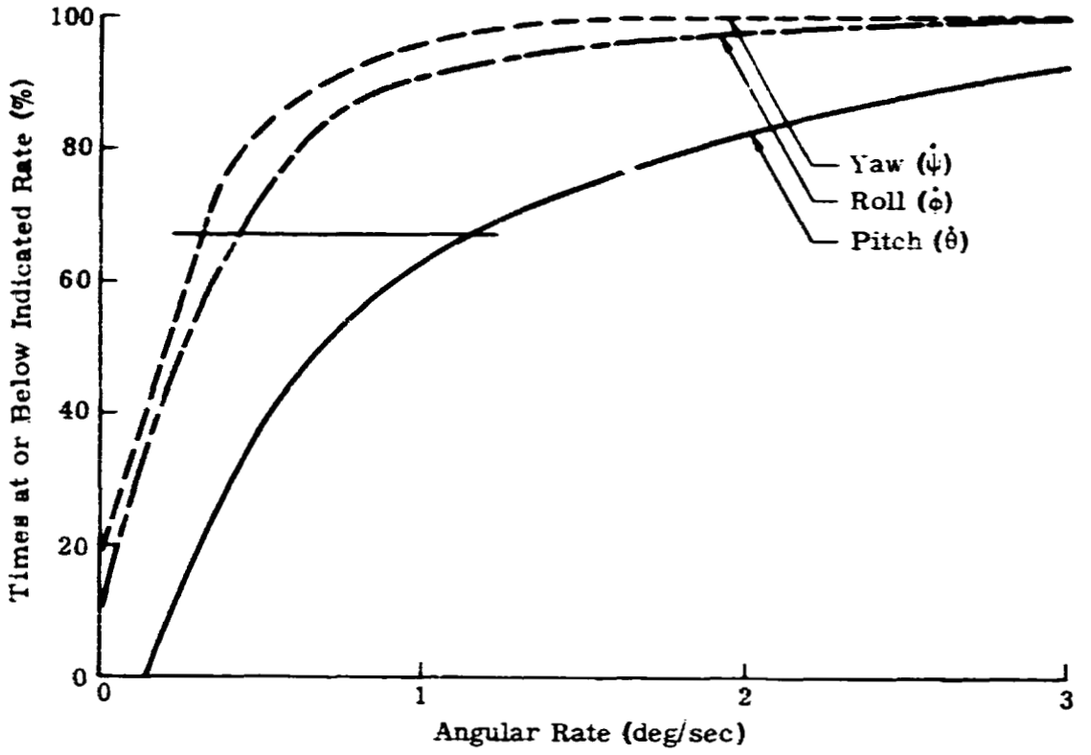


Fig. 48. Lunar Landing Terminal Body Rates--All Baseline Data

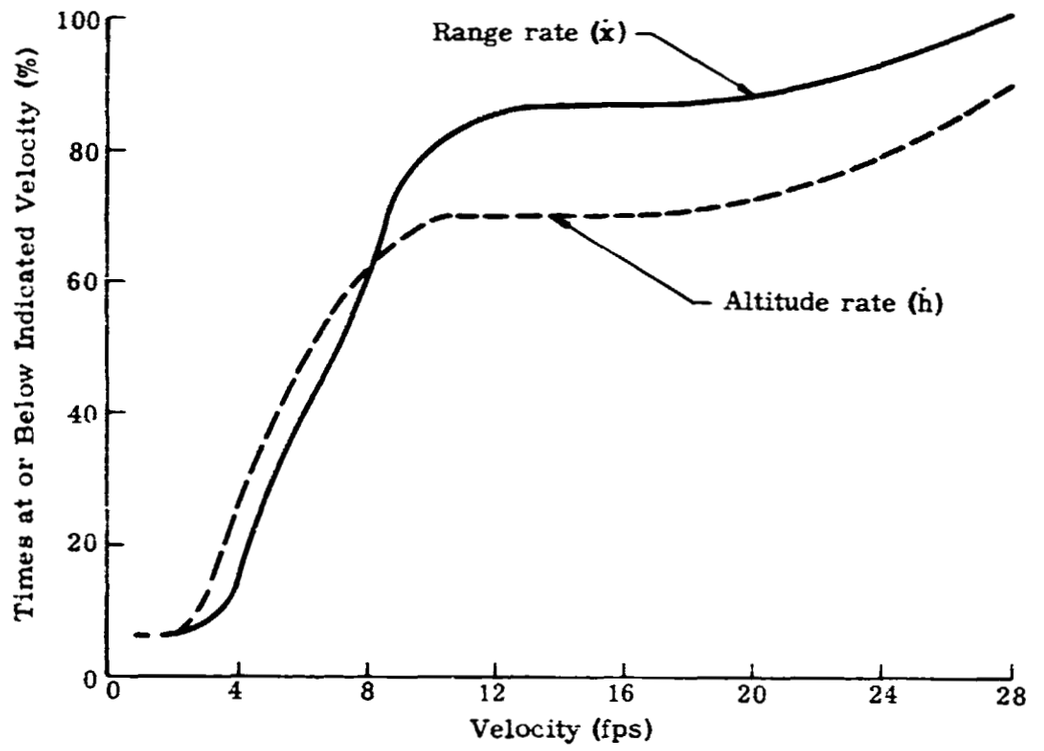


Fig. 49. Lunar Landing Terminal $\dot{h}$ and $\dot{x}$ for All Baseline Data--Pilot "A"

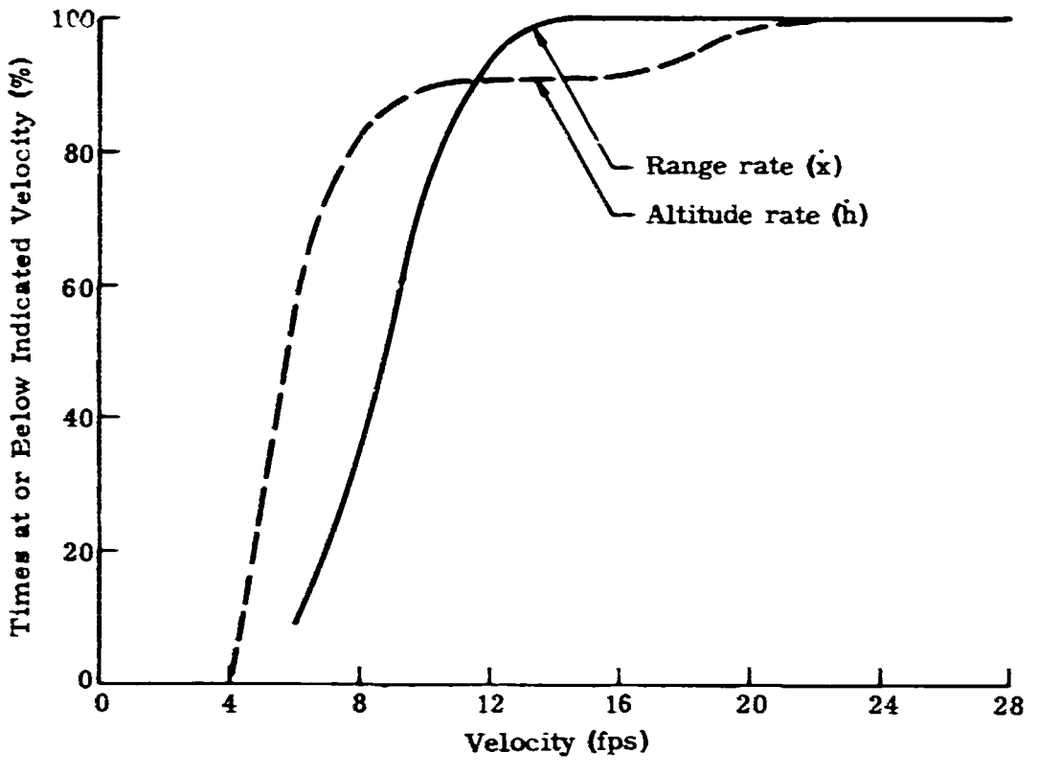


Fig. 50. Lunar Landing Terminal $\dot{h}$ and $\dot{x}$ for All Baseline Data--Pilot "B"

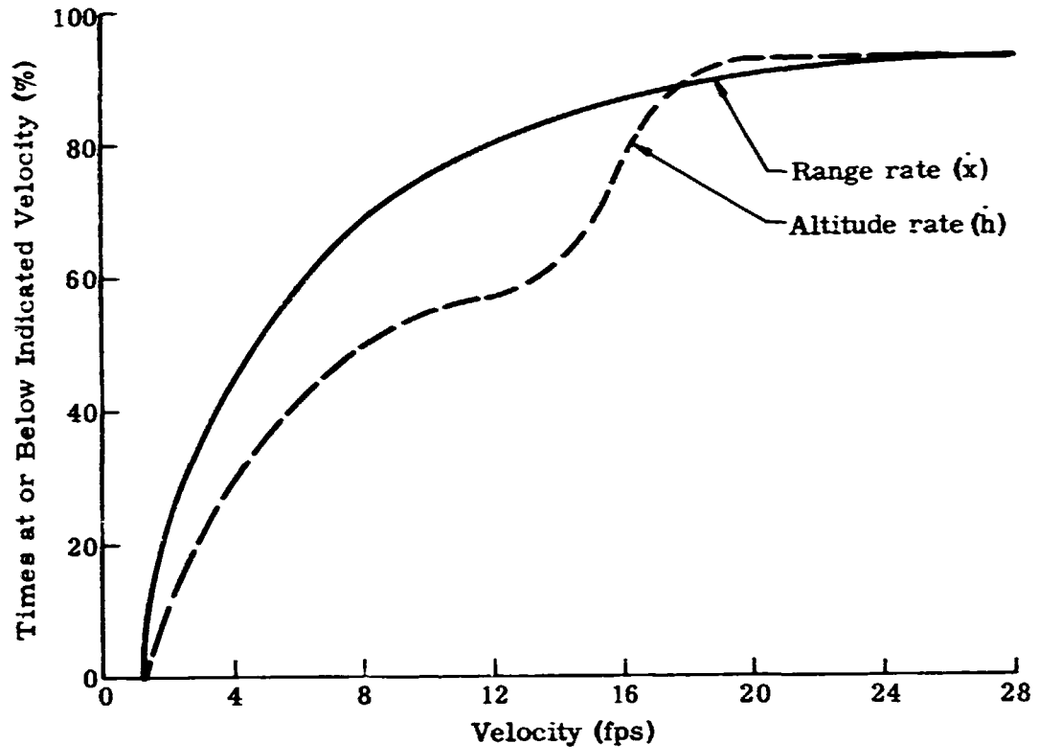
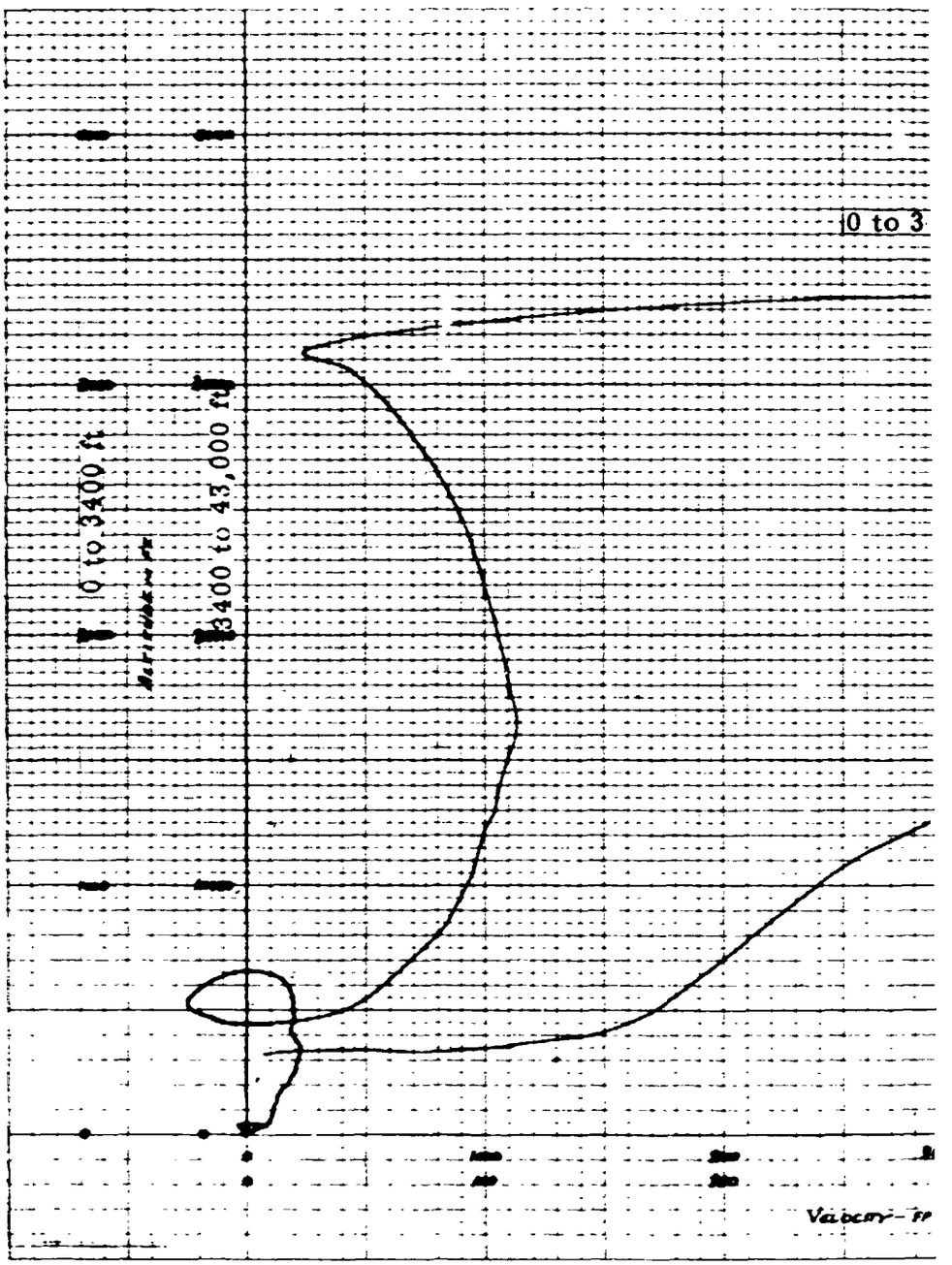


Fig. 51. Lunar Landing Terminal $\dot{h}$ and $\dot{x}$ for All Baseline Data--Pilot "C"


0 to 3
0 to 3400 ft
3400 to 43,000 ft

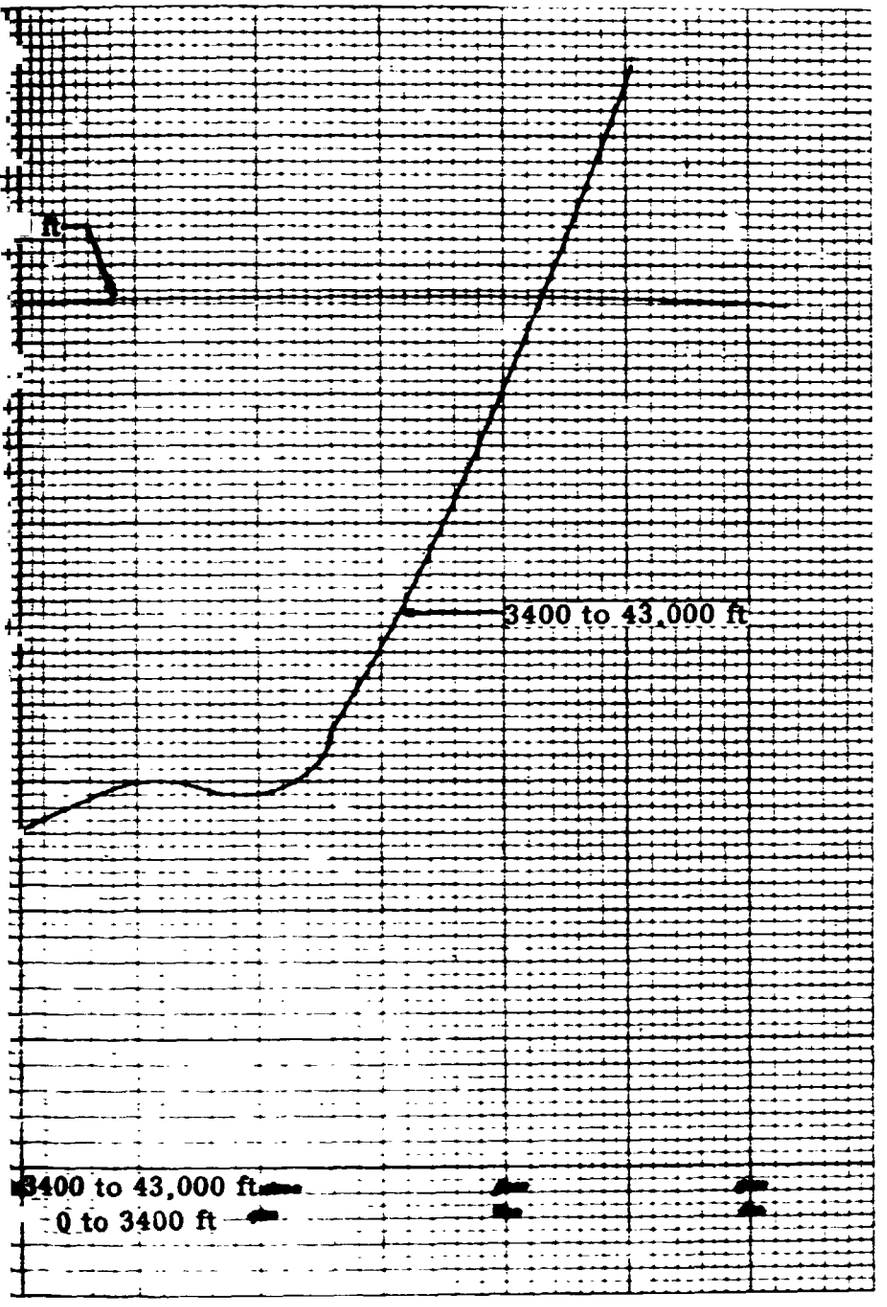


Fig. 52. Velocity Versus Altitude for Flight II Excursion Landing--Pilot "A"

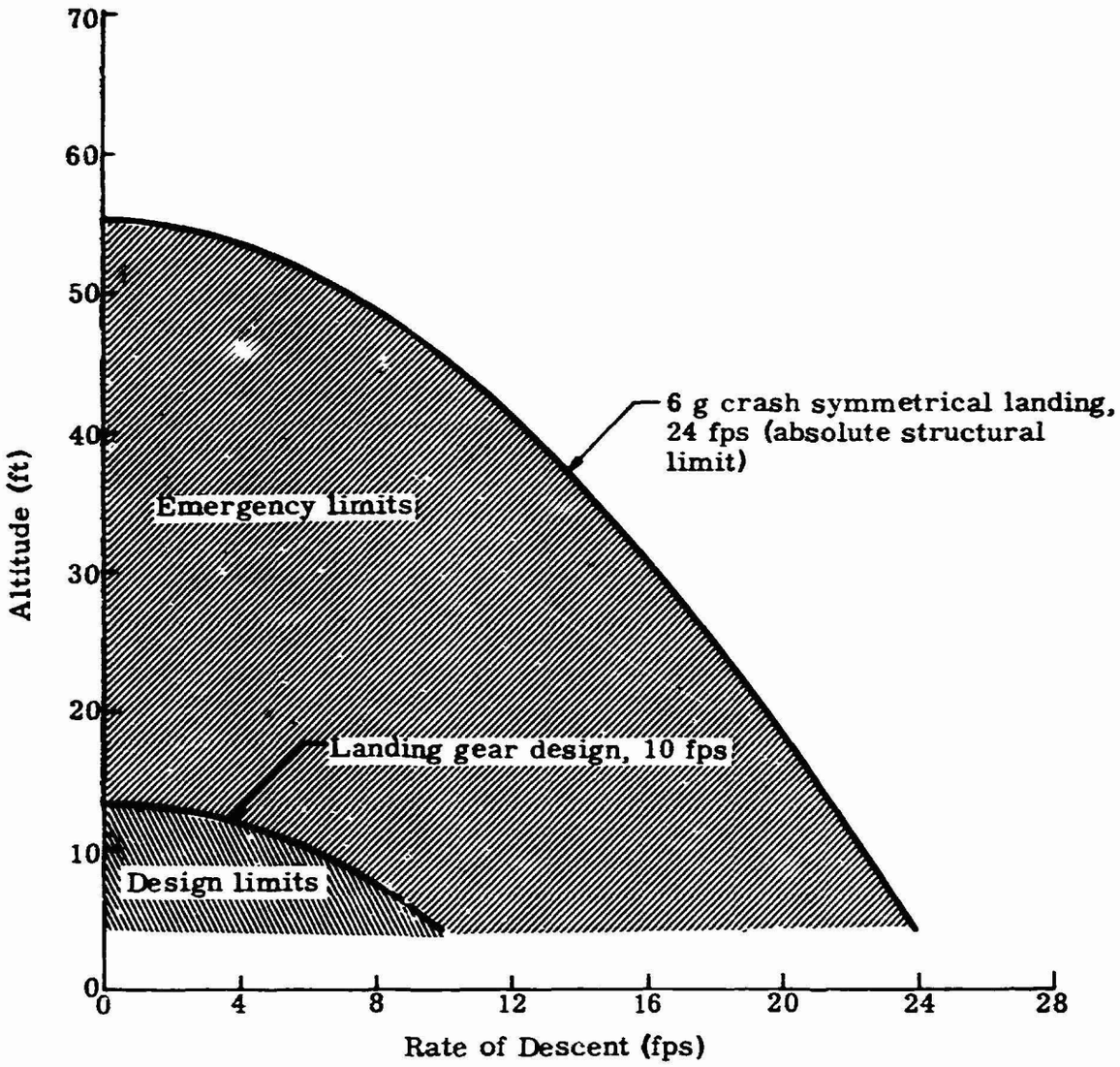


Fig. 53. Typical Landing Gear System Limitations

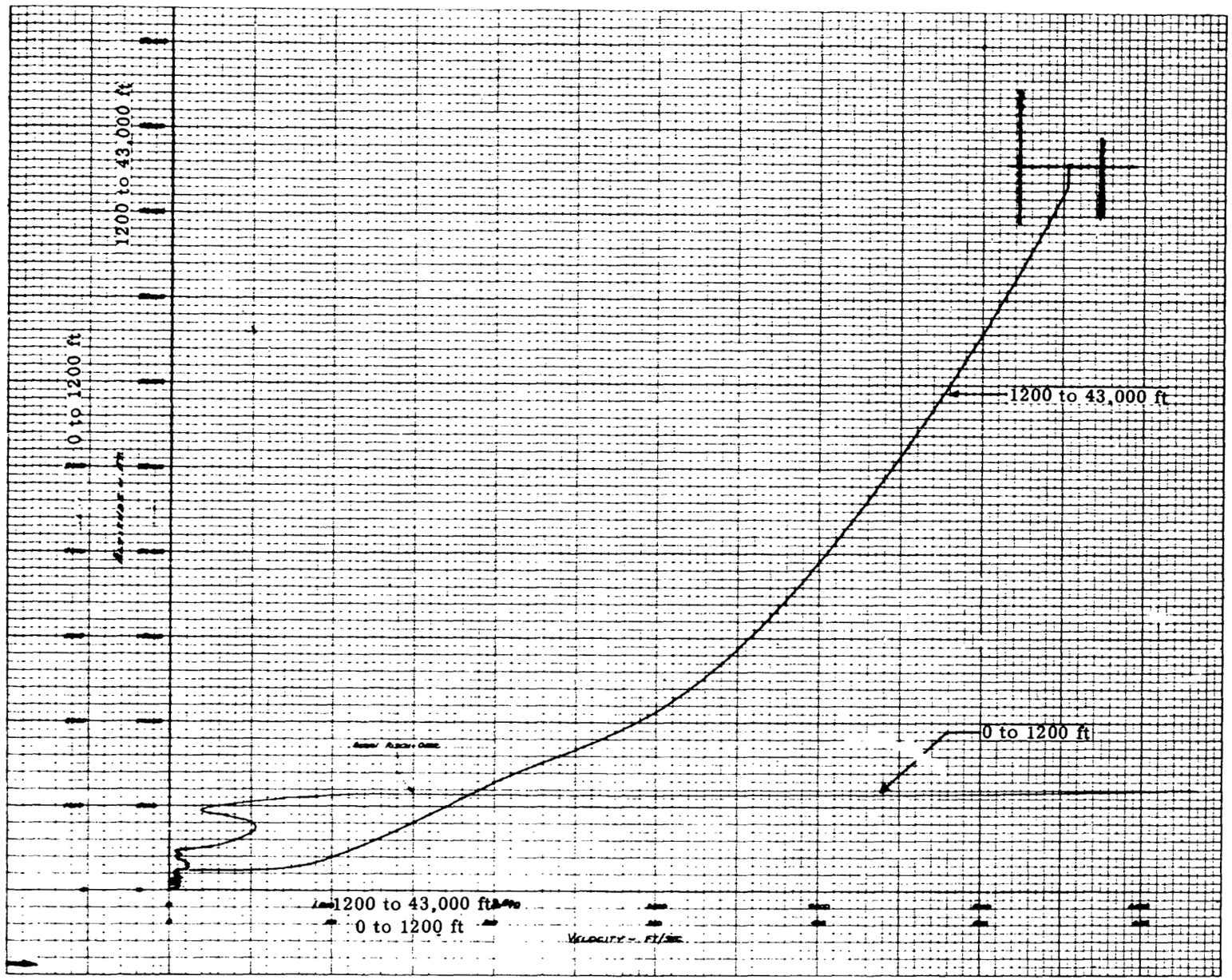


Fig. 54. Velocity Versus Altitude for Flight II Main Landing--Pilot "A"

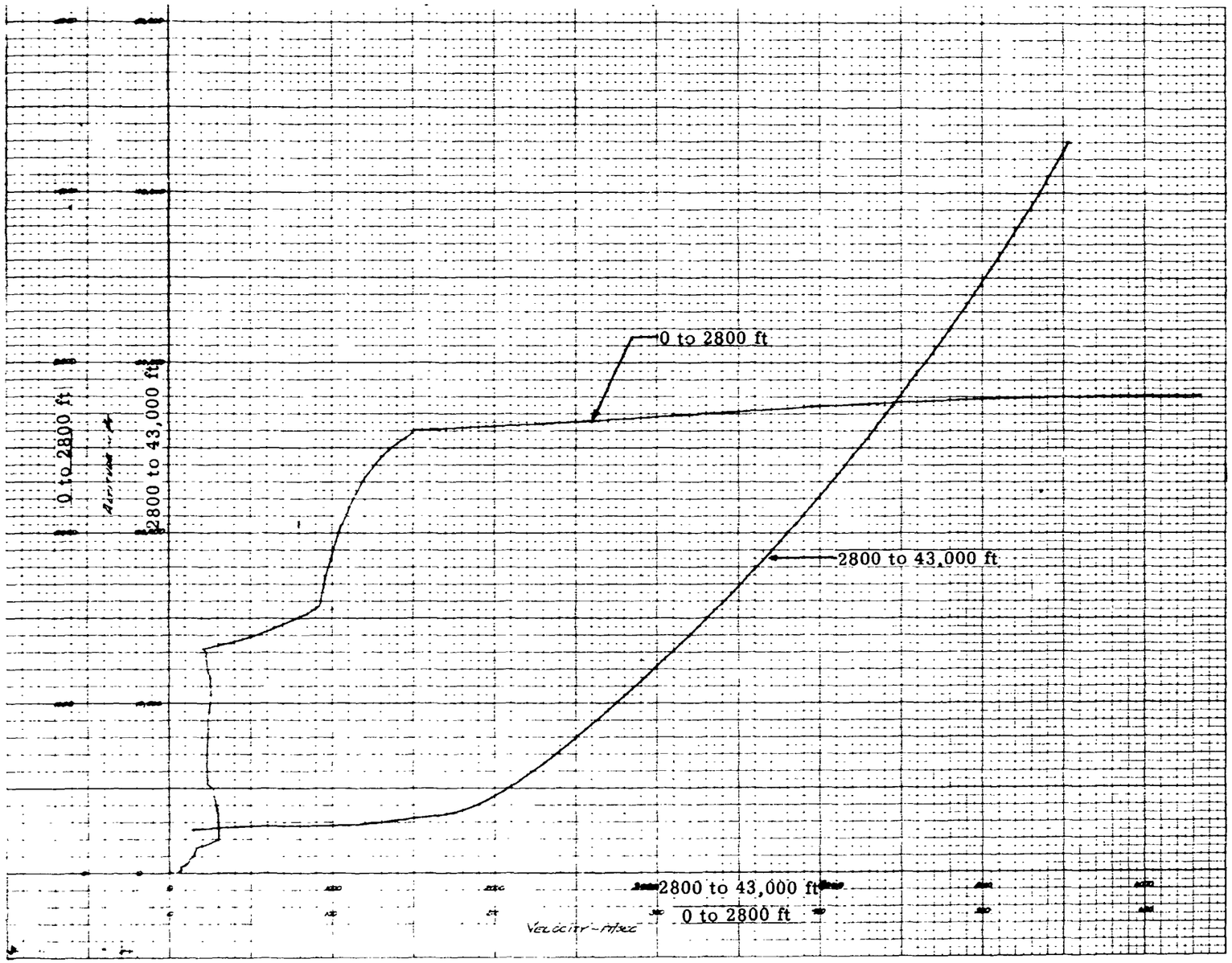


Fig. 55. Velocity Versus Altitude for Flight III Main Landing--Pilot "C"

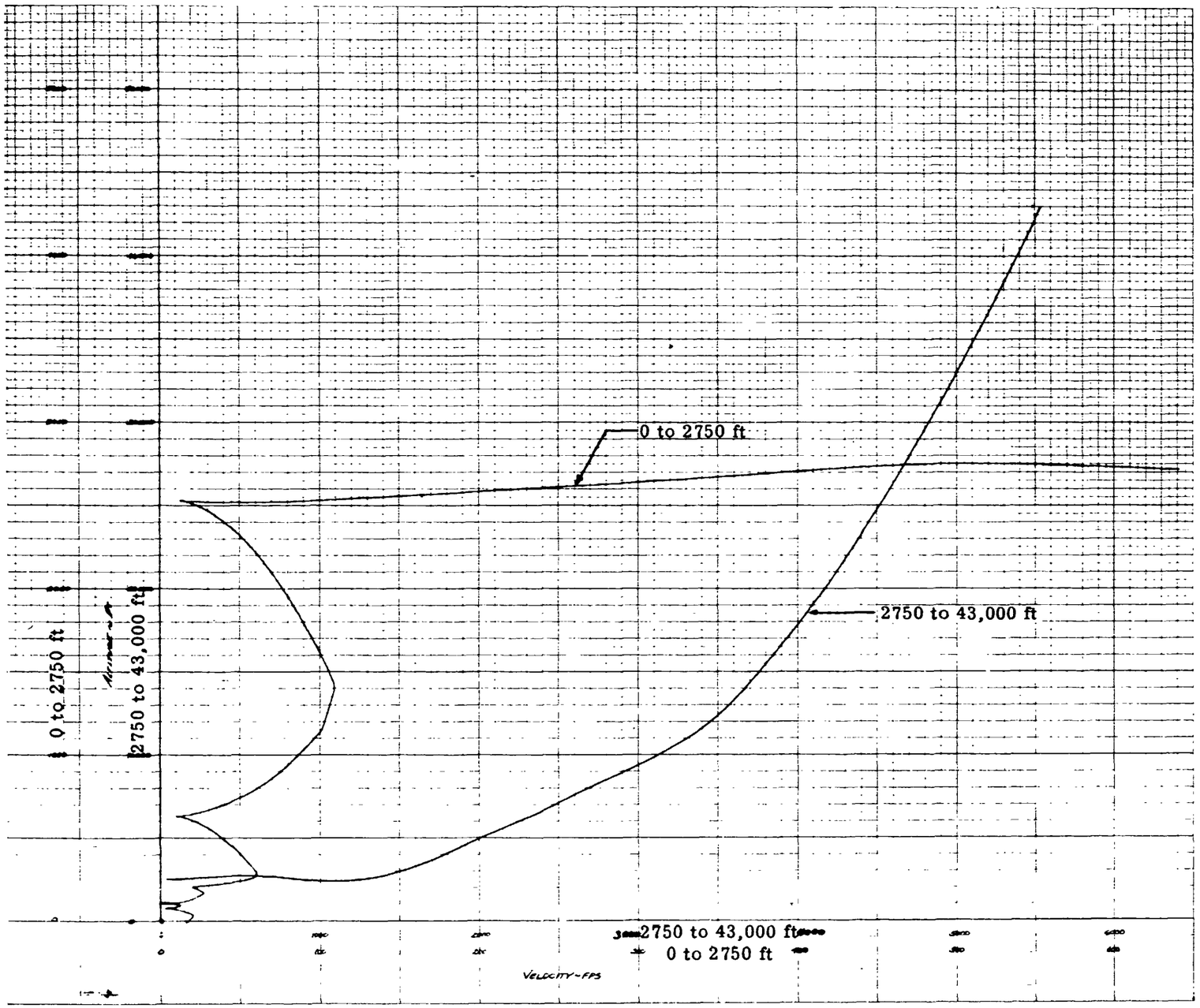


Fig. 56. Velocity Versus Altitude for Flight III Excursion Landing--Pilot "C"

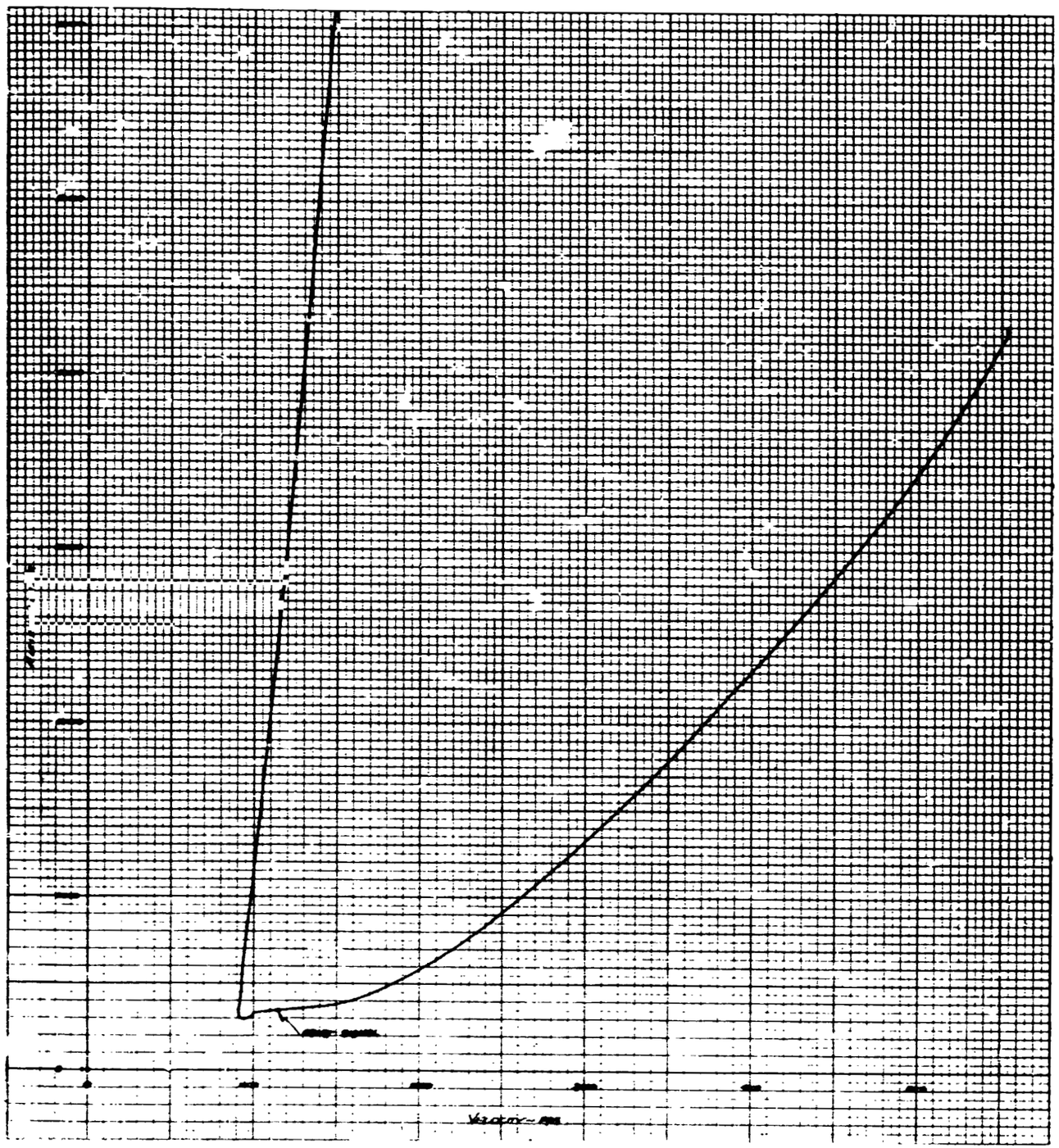
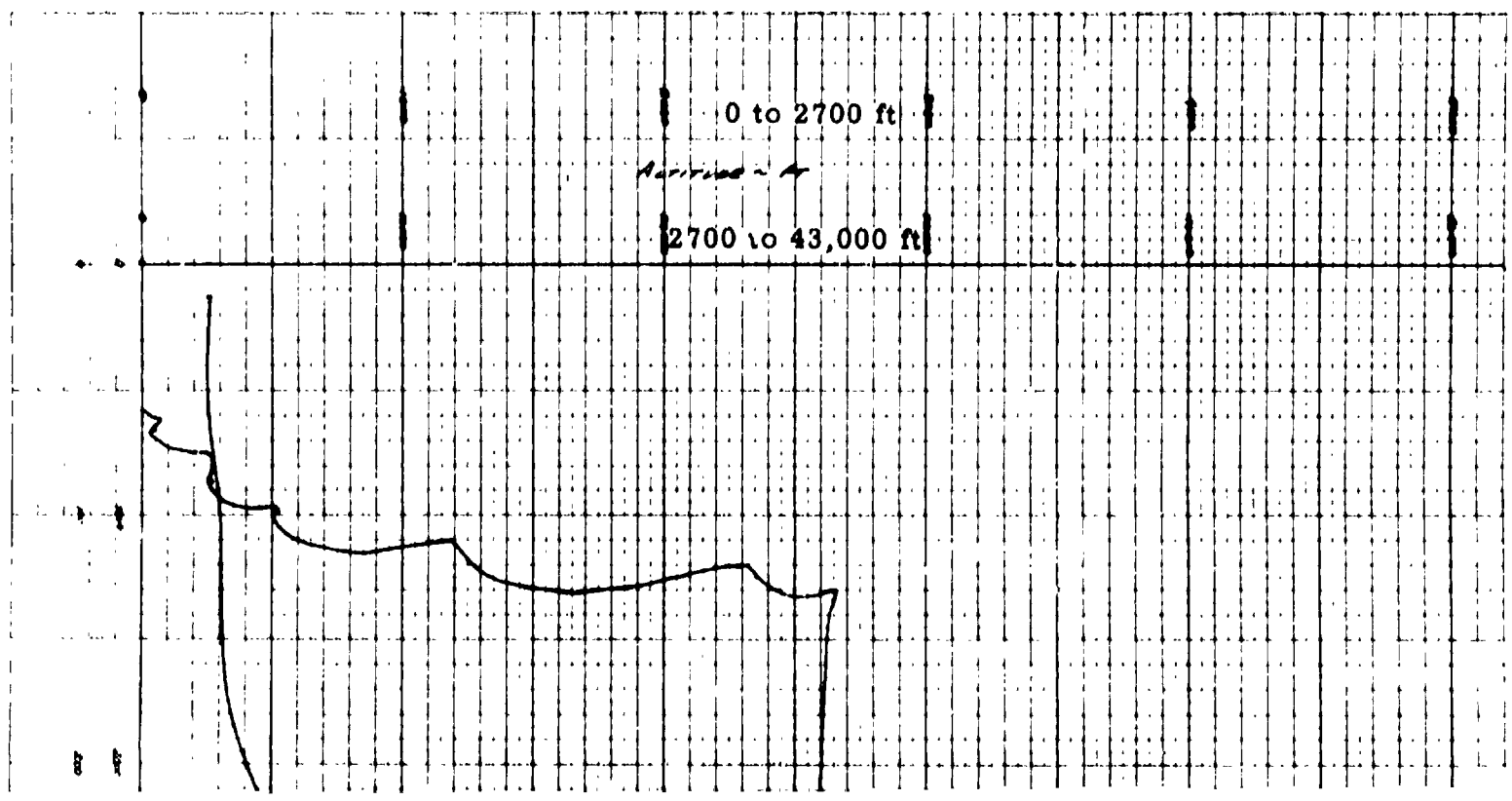


Fig. 57. Velocity Versus Altitude for Flight III Abort --Main Vehicle--Pilot "B"


0 to 2700 ft
2700 to 43,000 ft

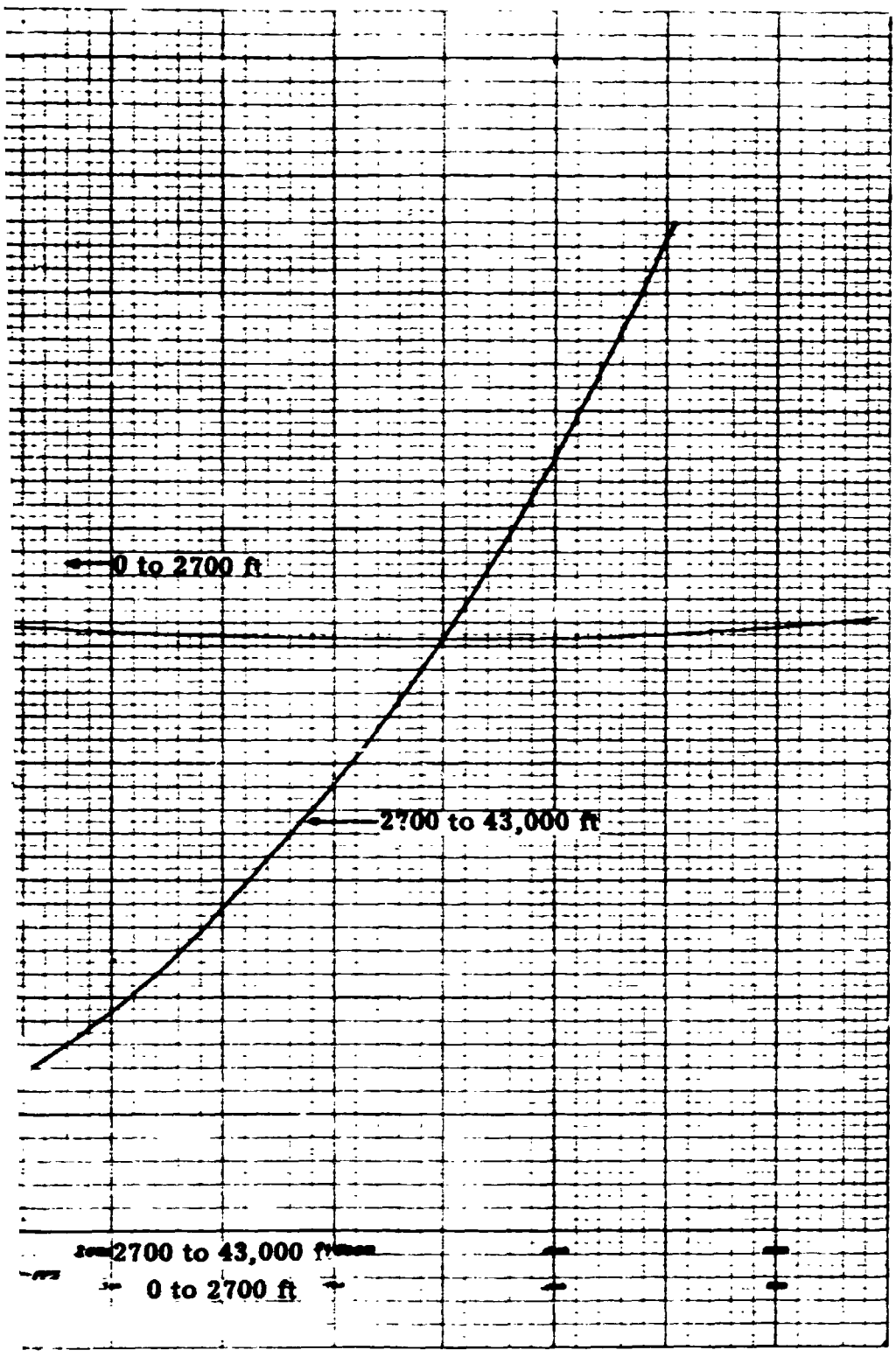


Fig. 58. Velocity Versus Altitude for Flight III Excursion Landing--Pilot "B"

LUMBAR LORIC VG — EXCURSION
FLEX 29°

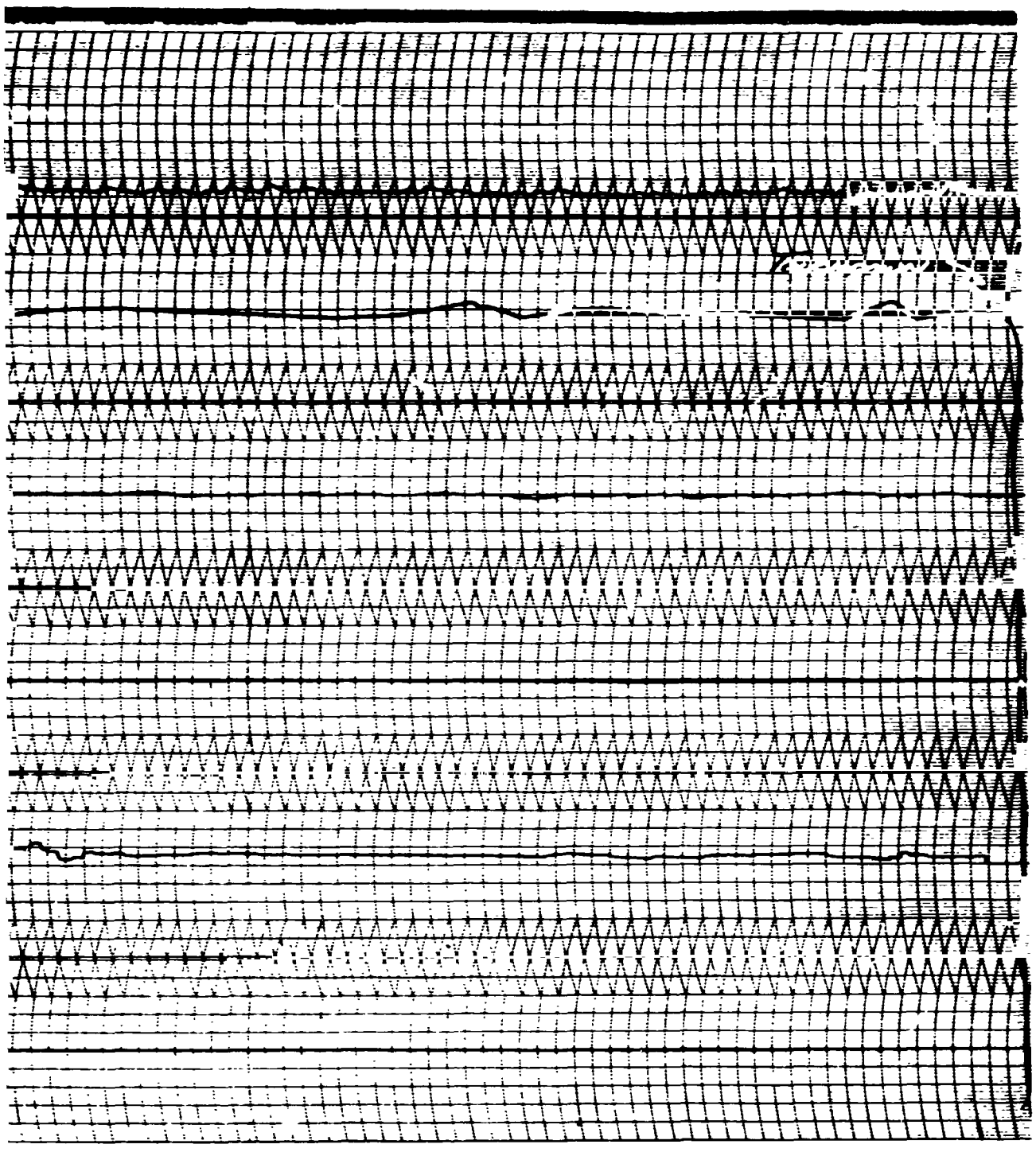
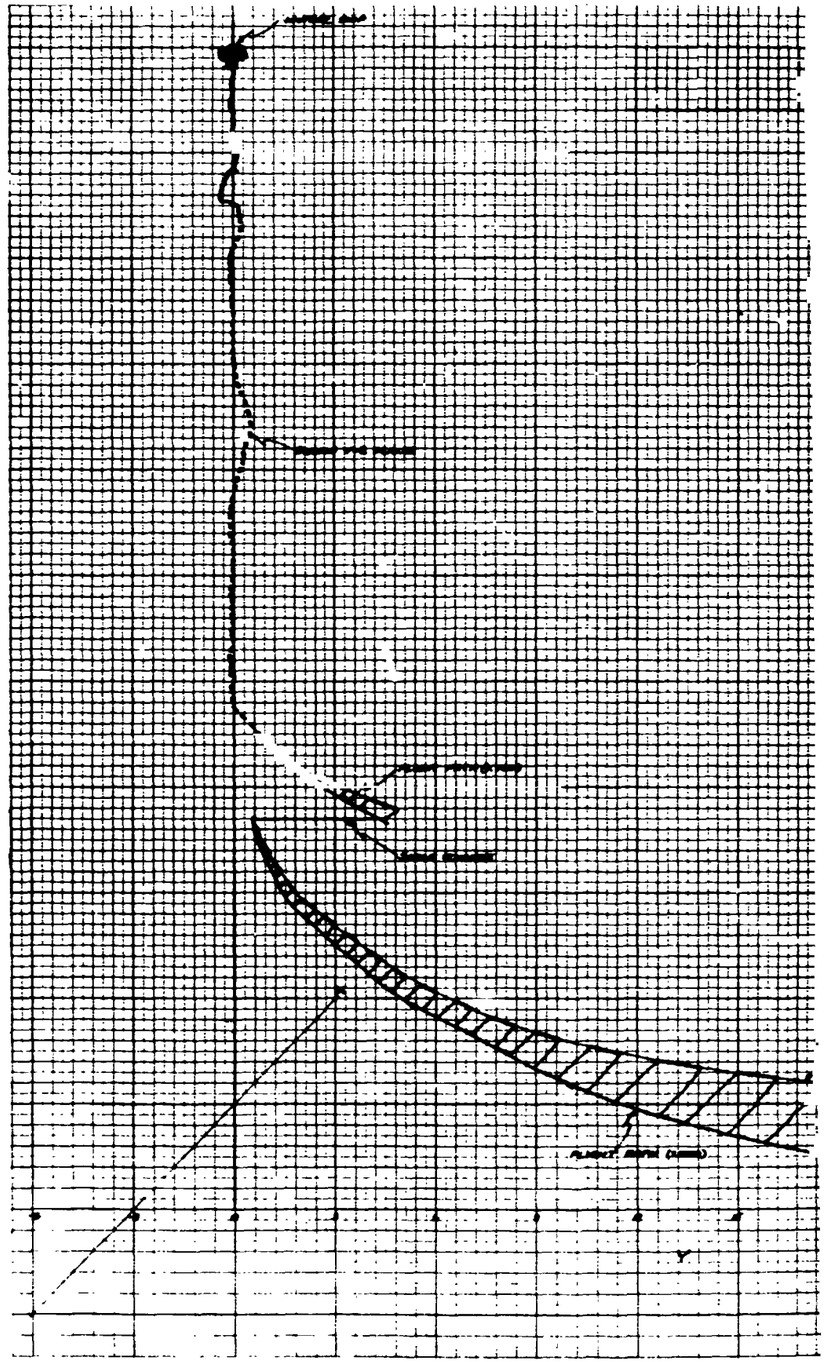
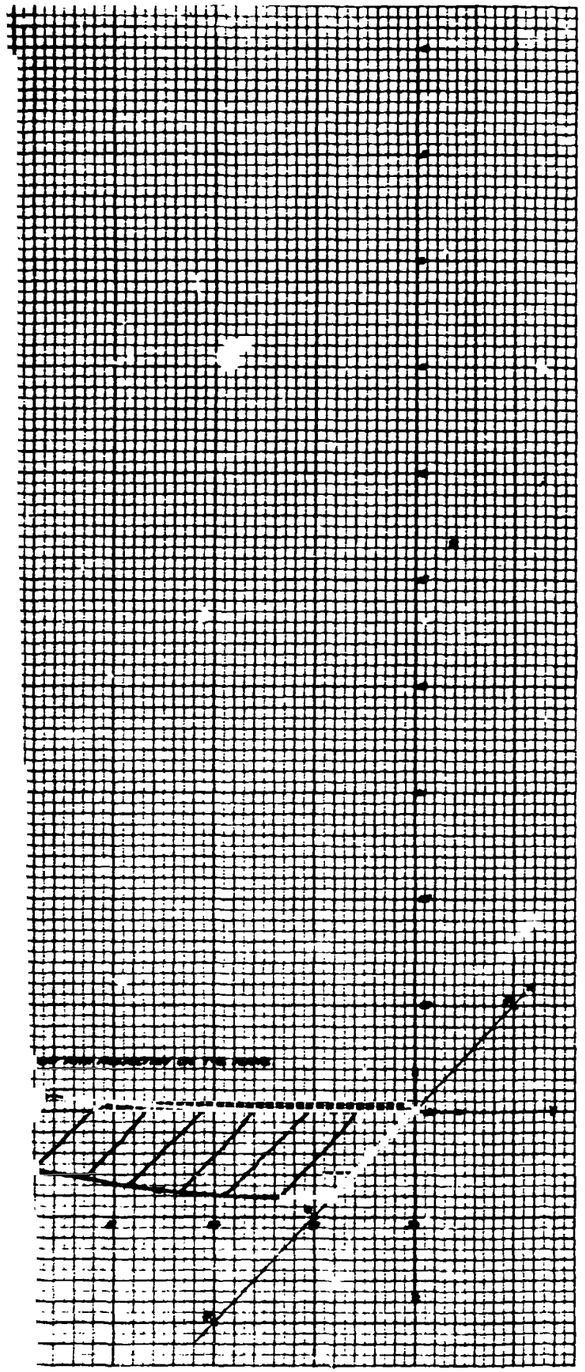


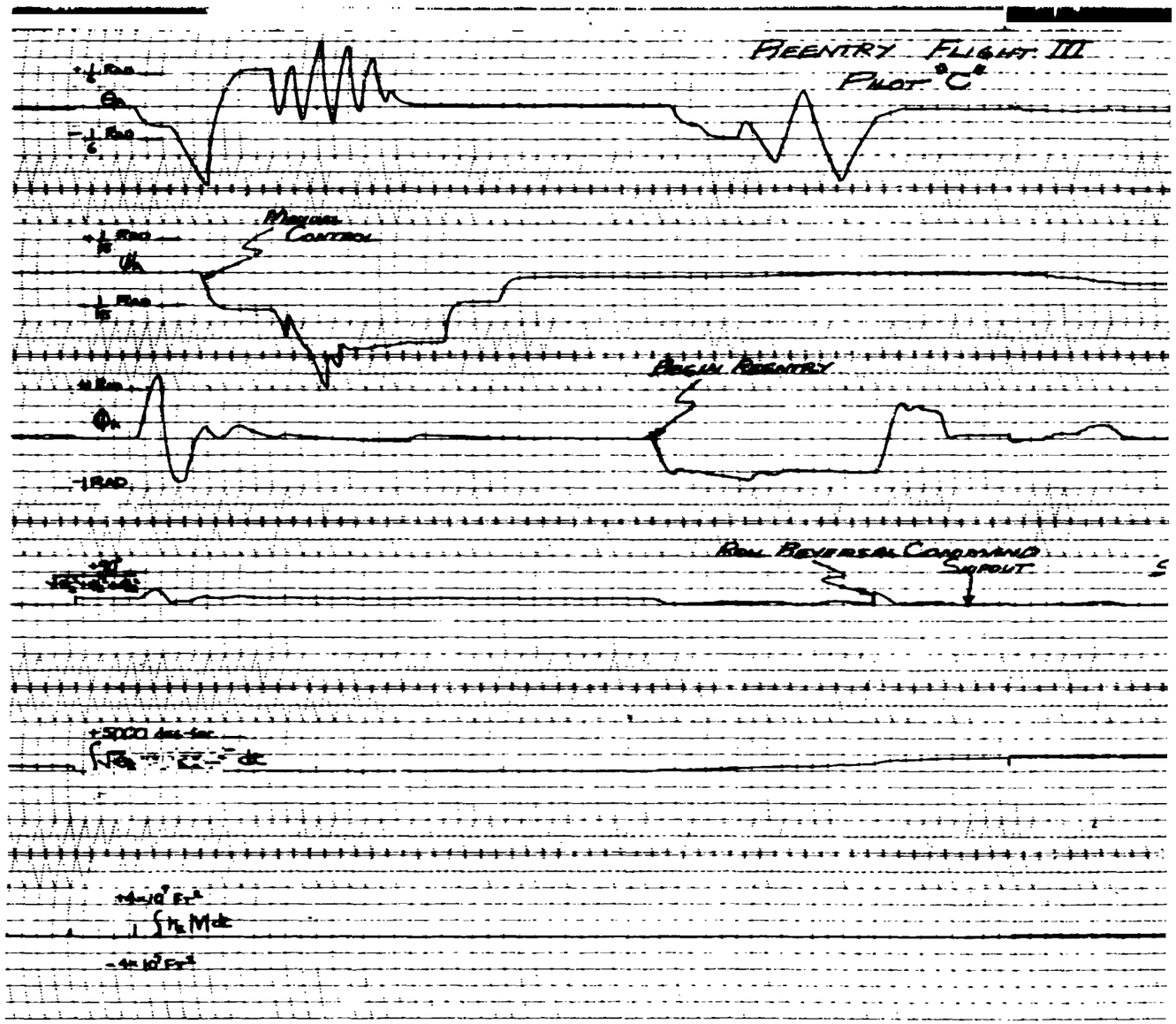
Fig. 59. Analog Flight Recording-- Excursion Vehicle--Lunar Landing





Re-entry

Fig. 60. "3-D" Rendezvous Plot for Flight III--Pilot "C"


REENTRY FLIGHT III
PILOT "C"
MANUAL CONTROL
BEGIN REENTRY
ROLL REVERSAL COMMAND SIGNOUT

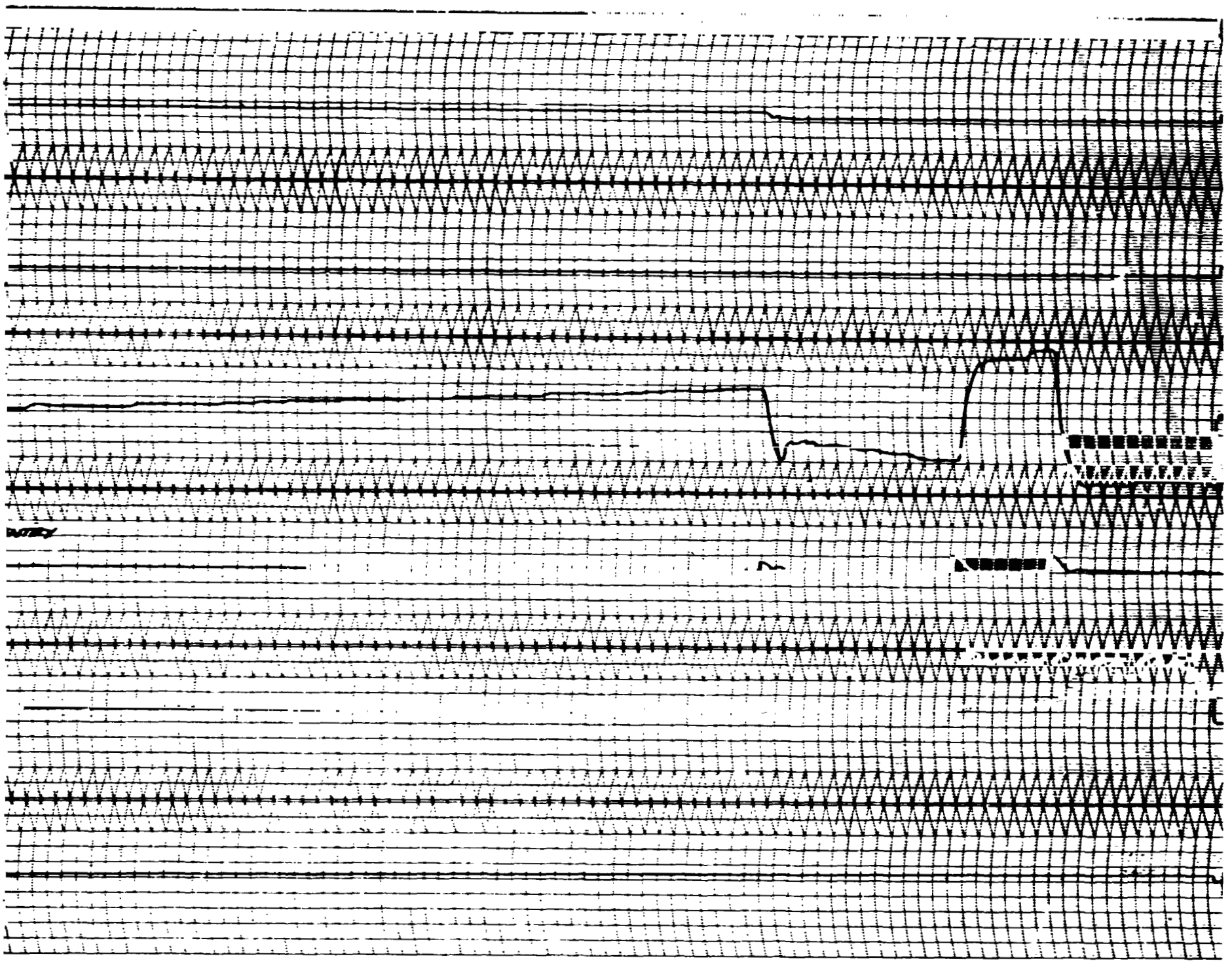


Fig. 61. Analog Flight Recording--Re-entry

Fig. 62. Tri-Sextant Operation

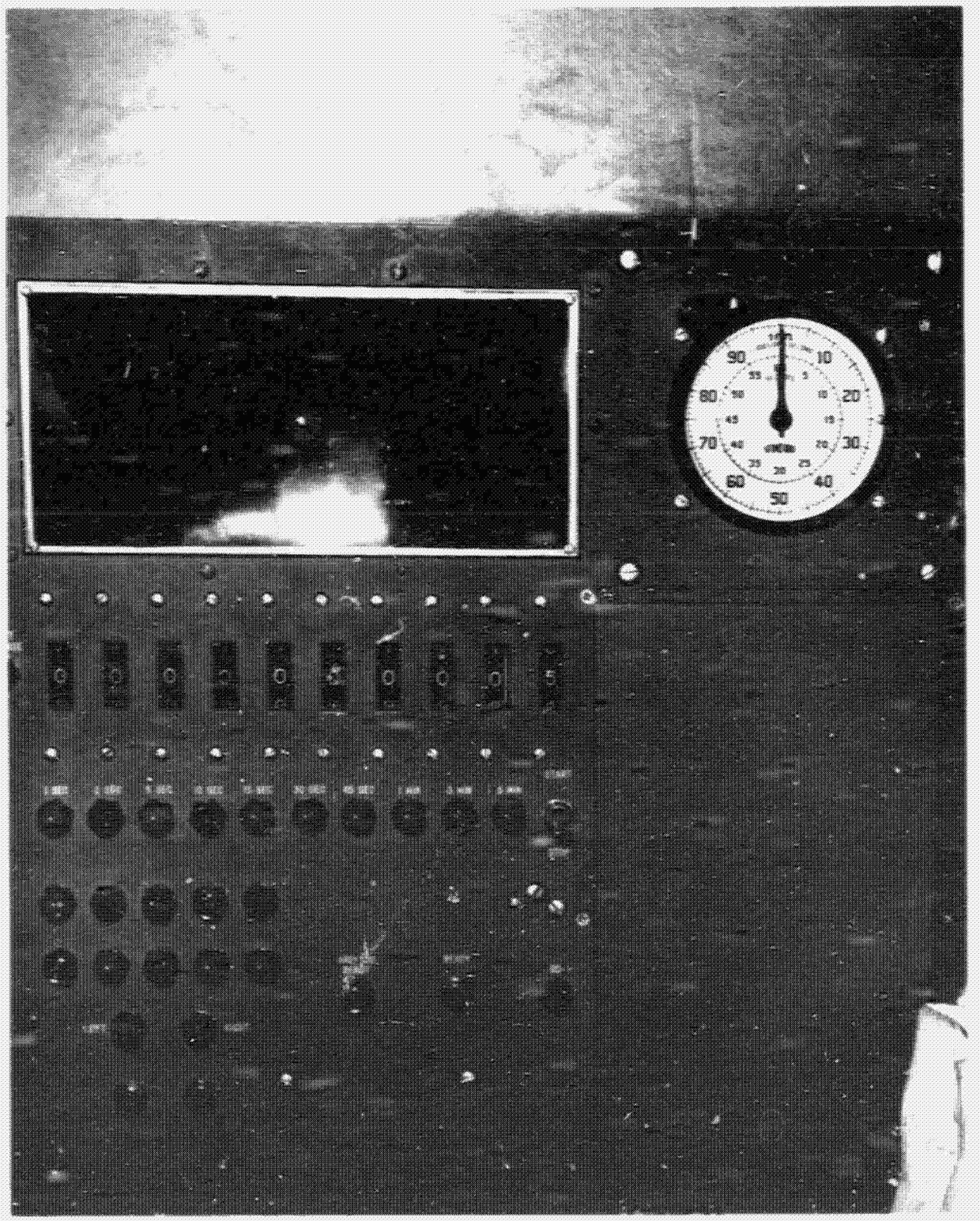


Fig. 63. Behavioral Response Panel

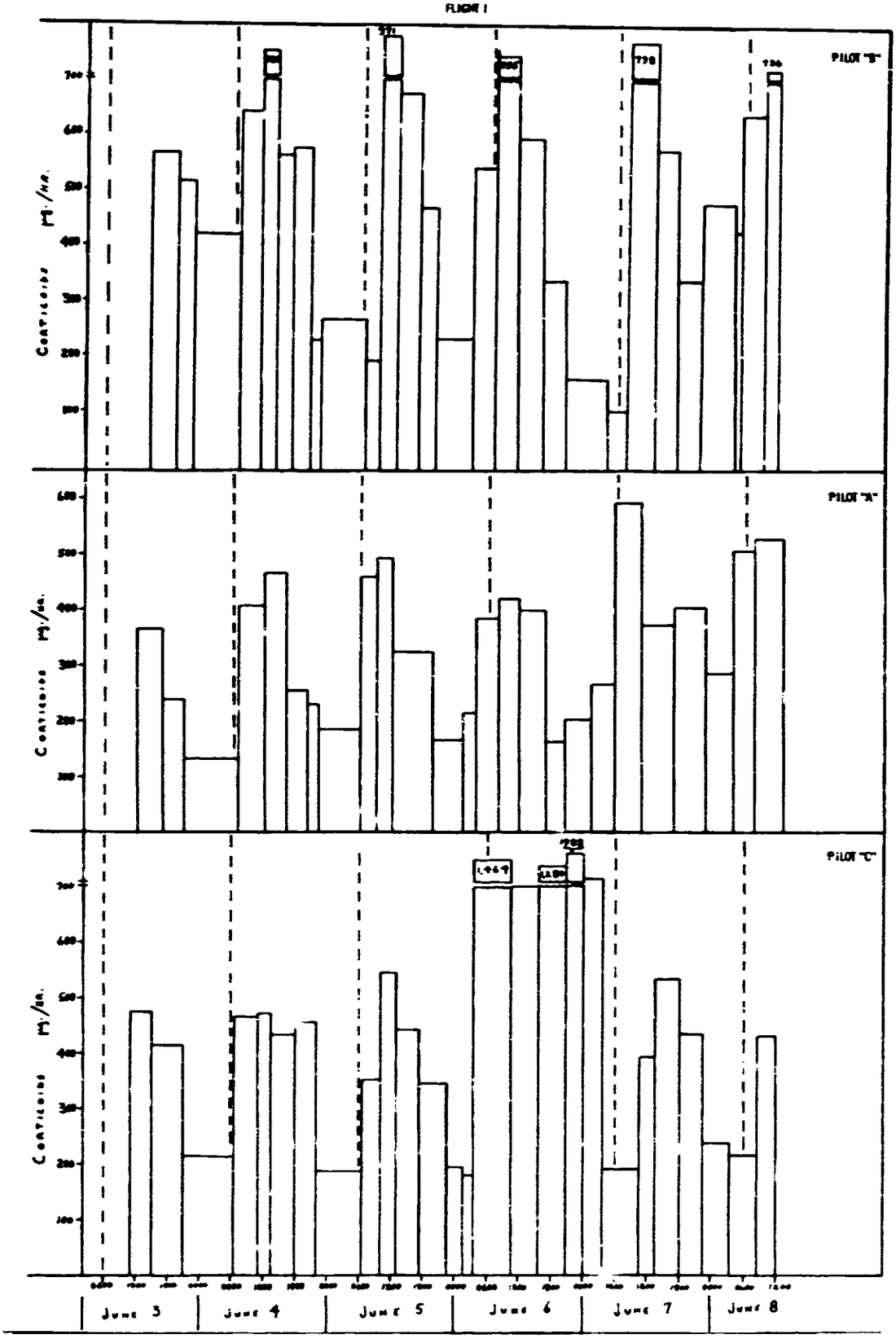


Fig. 64. Corticosteroids for Flight I

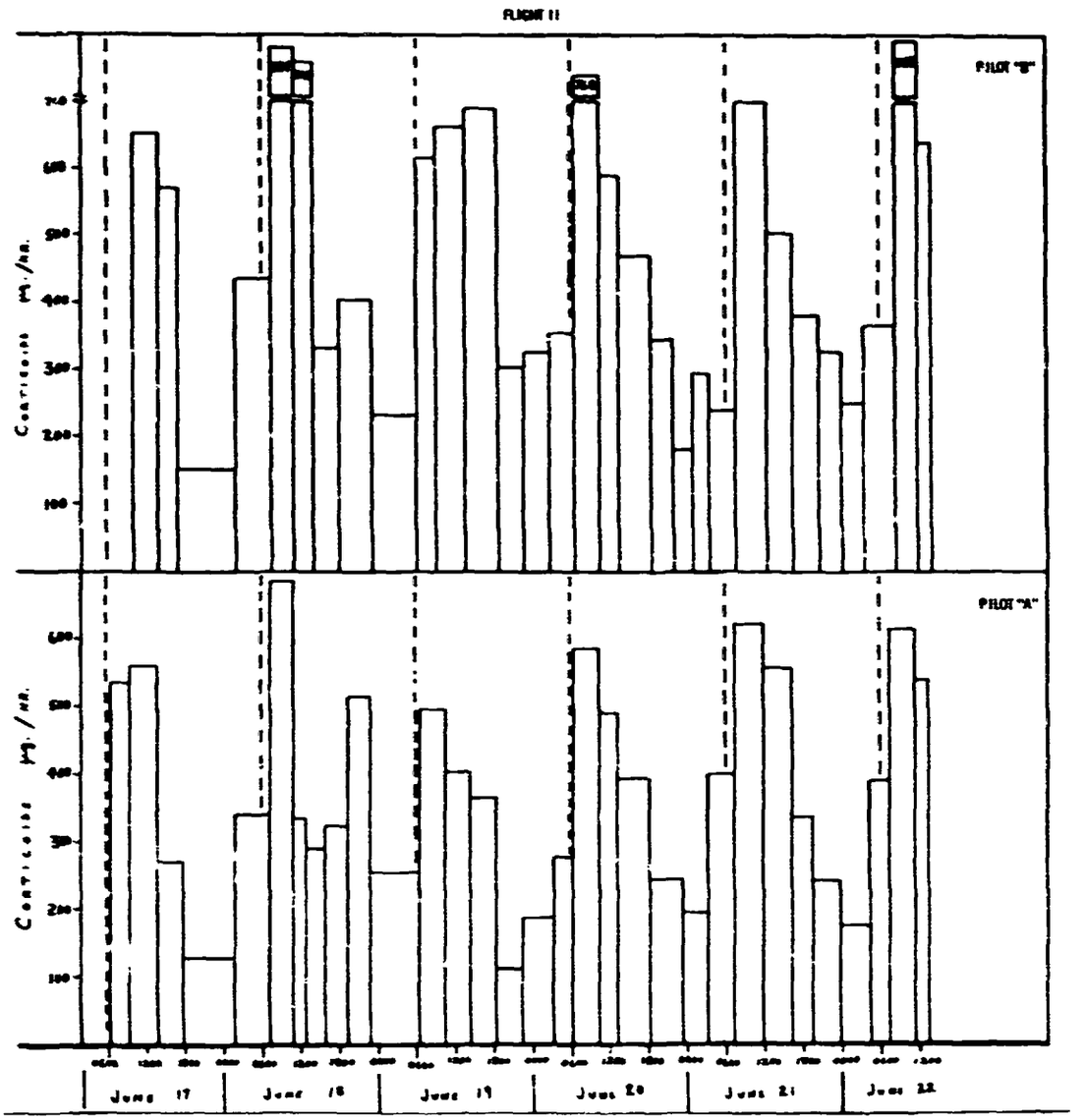
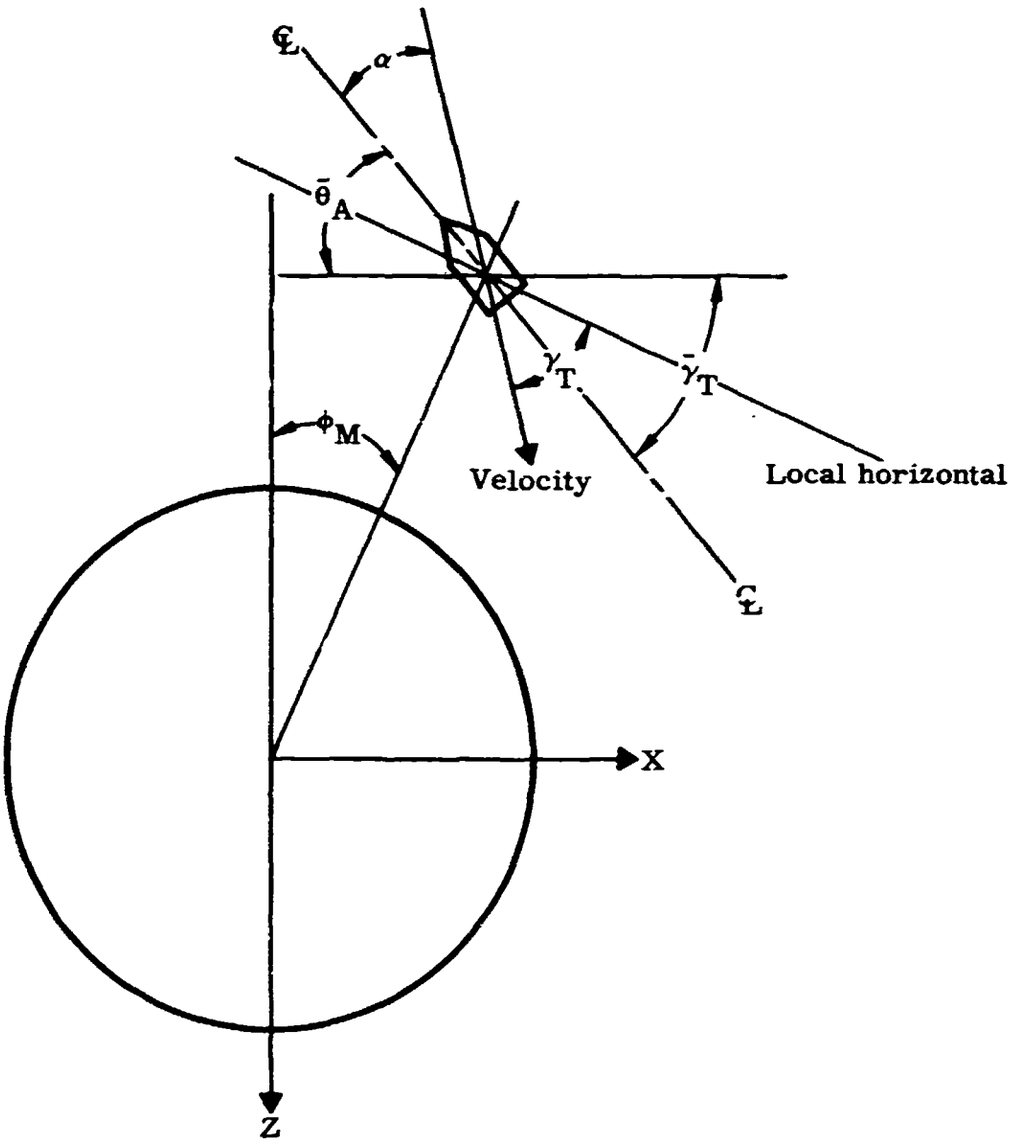


Fig. 65. Corticosteroids for Flight II



C-1. Lunar Landing Axis System